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Validation of NP Fertilizer Rates and Plant Population Density on Late Maturing Maize Variety at Jimma and BunoBedele zone, South Western Ethiopia

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Abstract

Maize is among the leading cereals in production globally and an important potential food security crop in Ethiopia. However, its productivity is very low mainly due to low soil fertility and plant stands per area. Thus, an on-farm experiment was conducted to validate the optimum rate of NP fertilizer and plant population density on late maturing maize variety at Jimma and BunoBedele Zone during 2019 main cropping season. Factorial combinations of two levels of N/P_2O_5 (92/69 and 115/86 kg ha^{-1}), and three plant population density [44,444(75*30cm), 53,333(75*25cm), and 66,666(75*20cm) ha^{-1}) were carried out in randomized complete block design using farmers field as replications. As a result, the highest grain yield 7410 kg $ha^{-1,}$ and above-ground biomass 17060 kg ha^{-1} were recorded from 66,666 plants ha^{-1} with the highest net benefit 44,138 Ethiopian Birr (ETB) ha^{-1}. Therefore, it is advisable for farmers in the study area and adjacent woredas' with similar agro-ecologies, a plant density of 66,666 plants ha^{-1} (75 x 20cm a plant $hill^{-1}$ or 75 x 40 cm two plants $hill^{-1}$) in complement with fertilizer rate of 92/69 kg N/P_2O_5 ha^{-1}.

Keywords: Chemical fertilizer, Grain yield and Plant population

INTRODUCTION

A significant proportion of maize in Ethiopia is produced in the highland areas. Its use, as well as area coverage, is increasing from time to time by replacing some cereals. Besides its use as a green cob, nowadays farmers use it as stable food by mixing with Tef for 'injera' and with wheat for bread [1]. Both the area and volume of production of maize have been growing steadily for the last decade throughout the highlands of Ethiopia. However, it suffers much from low soil fertility, poor management, and lack of improved varieties. As result, farmers produce a lower grain yield.

Among the principal problems, plant population densities and low soil fertility are the most bottlenecks that hinder maize productivity in the highland regions. Maize is commonly planted in rows of varying spaces; less effort has been made to study the optimum densities to maximize its productivity in different agro-ecologies of Ethiopia. Summaries of earlier results from different studies on maize plant population densities indicate that better yields were obtained at planting density in the range of 4-7 plants m^{-2} (40,000-70,000 plants ha^{-1}) [2]. Later studies confirmed that at 5-7 plants m^{-2} medium to late maize maturity groups gave maximum yields in humid regions, while early maturity groups produced maximum yields at higher densities in both humid and moisture stress areas [3]. It is being observed that late maturing maize varieties were found to be varied in structure and leaf arrangements from early and medium maturing maize varieties. These variations in morphology may lead to different planting densities to attain maximum yield potentials.

Plant population is the prime factor for getting maximum yield which is decided by inter and intra row spacing of crops. Decreasing the distance between neighbor rows at any particular plant population reduces competition among plants within rows for light, water and nutrients due to a more equidistant plant arrangement [4].The more favorable planting pattern provided by closer rows enhances maize growth rate early in the season [5], leading to a better interception of sun light, a higher radiation use efficiency and a greater grain yield [6]. Increasing plant populations could lead to increase yields under optimal climatic and management conditions due to greater number of smaller cobs per unit area [7].

Nutrient depletion and soil degradation have become a serious threat to agricultural productivity in Ethiopia. These soils suffered multi-nutrient deficiencies so that, application of mineral fertilizers has become indispensable to increase crop yields in such soils [8].

According to Srikanth et al. [9] among the plant nutrients, primary nutrients such as nitrogen and phosphorus play a crucial role in determining the growth and yield. The nutrient use efficiency can be proved with the use of hybrids, optimum plant population and application of chemical fertilizer coinciding with peak need by the crop. Hence, the experiment was done to validate the effect of NP fertilizer rates and plant population density on maize at Jimma and BunoBedele Zone; and to identify the economic optimum rate of NP fertilizer and plant population density for the production of maize.

Materials and Methods

Description of the Study Area

The experiment was conducted in two sites of Jimma Zone (Kersa and Omonada woreda) and Buno-Bedele Zone (Banshure kebele), Southwestern Ethiopia during the main cropping season of 2019. The Kersa site was located on latitude 7º42' N and longitude 36º 59'E and laid at an altitude of 1753 m.a.s.l. The average minimum and maximum temperature are 6ºC and 25.5ºC respectively and reliably receive good rains 1712 mm per annum during the cropping season. Whereas, Omonada site was located on latitude 7º37' N and longitude 37º 14'E and laid at an altitude of 1753 m.a.s.l. The average minimum and maximum temperature are 6ºC and 25ºC respectively and reliably receives good rains 1446 mm per annum cropping season. The Bedele site was located on latitude 8º32' N and longitude 36º 22'E and laid at an altitude of 1753 m.a.s.l. The average minimum and maximum temperature is 6ºC and 24.5ºC respectively and reliably receive good rains 1712 mm per annum during the cropping season. The farming system of the study site is coffee and cereal crops dominated with coffee, maize, teff and sorghum also have warm and cold climate, also convenient topography is very suitable for all agricultural practices. It was situated in the tepid to cool humid-mid highlands of southwestern Ethiopia. The soil type of the experimental area was Eutric-nitisols (reddish-brown).

Soil Physico-chemical Properties

The soil of the experimental field was characterized by selected physico-chemical properties before the application of the treatments (Table 1). The average soil pH of the trial sites ranges from 5.06 to 5.11 across locations, which was strongly acidic [10] and ideal for the production of most field crops. The pH of the soil affects maize growth by suppressing the root development and reducing the availability of macronutrients to plants especially phosphorus [11]. The soil total N ranges from 0.14 to 0.21% and SOM from 3.34 to 3.94% were found to medium rate for crop growth and development for both nutrients [12]. For all locations the Bray II extractable available P ranges from 2.76 to 7.30 mg kg^{-1} which was below the critical level (8 mg kg^{-1}) for most crops as described by Tekalign and Haque [13].

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

Soil characters	Location		
	Kersa	Omonada	Bedele
pH(1:2.5)	5.11	5.06	5.10
Av P(mg kg^{-1})	2.76	7.30	6.38
TN (%)	0.14	0.18	0.21
OC (%)	2.29	1.94	2.15
SOM (%)	3.94	3.34	3.70
C:N ratio	16.09	10.74	10.21

Where pH= hydrogen power, OC=Organic carbon, TN=Total Nitrogen, Av P=Available Phosphorous, SOM=Soil Organic Matter. Values are the means of duplicated samples.
Source: Jimma Agricultural Research Center soil and plant laboratory

Description of the experimental materials

Hybrid maize variety BH661 was used in the present study. It is the most promising variety released by Bako Agricultural Research Centre and adapted well to the agro-ecologies of Jimma and Buno Bedele areas.

Experimental treatments and procedures

The experimental field was plowed and prepared following the conventional tillage practice before planting at all locations. The land was leveled using manual power before the field layout was made. The maize was planted from 18 up to 22 May at different locations. Two maize seeds were planted per hill and then thinned to one plant per hill after the good establishment of seedlings to maintain a single healthy plant per hill. This experiment had six treatments with farmer's field replications which were two NP_2O_5; 92/69 and 115/86 kg ha^{-1} and three plant population densities; 44,444, 53,333 and 66,666 plants per hectare. A total of 6 treatments were laid out in a factorial randomized complete block design.The plot size $45m^2$ (4.5 m x 10 m) was used for each treatment.

Nitrogen and phosphorus fertilizers were applied, respectively per stand or hill base. Nitrogen fertilizer rates were applied during the planting and knee height stage to increase the nitrogen use efficiency. All other agronomic practices were applied uniformly to all experimental plots in the study area.

Data collected

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.

Number of ears per plant: it was obtained by counting the total number of ears in each plot and divided to a total number of plants stand harvested.

Stem diameter (girth): it was measured at 50cm from the ground level on six randomly selected plants using a caliper.

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.

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.

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.

Harvest index: was calculated as the ratio of grain yield to above-ground biomass yield on a dry weight basis [14].

$$\mathrm{HI}(\%) = \frac{\text{Economic yield (kg/ha)}}{\text{Total biological yield (kg/ha)}} \mathrm{x}100$$

Data analysis

Analysis of variance (ANOVA) for all collected data was computed using SAS version 9.3 statistical software. Whenever the ANOVA results showed the significant differences between sources of variation, the means were compared using the least significant difference. The homogeneity test was done as suggested by Gomez and Gomez, [15].

Partial budget analysis

The Partial budget analysis was performed to investigate the economic feasibility of the treatments and assess the costs and benefits associated with different treatments of chemical fertilizers and the seed rates. The partial budget technique as described by CIMMYT [16] was applied. The partial budget analysis was done using the prevailing market prices for inputs at planting and outputs at the time the crop was harvested. All costs and benefits were calculated on a hectare basis in Ethiopian Birr (ETB). The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment, the gross field benefit (GFB) ha^{-1} (the product of field price and the mean yield for each treatment), the field price of chemical fertilizers and urea kg^{-1} (the nutrient cost plus the cost of transportation from the point of sale to the farm), cost of labor spent on seed purchase and planting, the total costs that varied (TVC) which included the sum of field costs of fertilizers and their application, and seed purchase and planting.

The open market price (7 birr kg^{-1}) for maize crop and the official prices of NP fertilizer (13.5 birr kg^{-1}), urea (10 birr kg^{-1}) and the cost of labor spent on chemical fertilizer application, seed planting and purchase were used for analysis. The cost of application and transport for fertilizer was taken to be 15 birr 100 kg^{-1}. Grain yield was adjusted by 10% for management difference to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment [17], [16].

Results and Discussions

After three years experiment of NP fertilizer rates and plant population density on late maturing maize variety, further evaluation and validation was done at nine farmers' sites during 2019 main cropping season at Jimma zone Omonada and Kersa woreda; and Bedele zone Bedele woreda.

The homogeneity test of the error variances for locations indicated that the error variance was homogenous and hence combined analysis of variance was conducted. Statistical analysis revealed that the interaction and main effect of NP fertilizer rates didn't show significant (P >0.05) difference on plant height, number of ears per plant, stem diameter (girth), lodging percent, grain yield, aboveground biomass and HI. However, the main effect of plant population density was highly significant (P ≤0.01) on plant height, number of ears per plant, grain yield and aboveground biomass. Whereas, stem diameter (girth) and plant lodging were significantly (P ≤0.05) influenced by plant population density. However, harvest index were not significantly (P >0.05) affected by plant population density (Table 2).

Table_2: Mean square values of NP fertilizer rates and plant population density on growth, yield components and yield of maize

Parameter	Mean square for source of variation			
	NP (1)	Population density (2)	NP x Population density (2)	Error (40)
Plant height(cm)	75.85^{ns}	425.41**	20.96^{ns}	82.54
Ears per plant	0.0096^{ns}	0.0707**	0.0011^{ns}	0.0116
Girth(cm)	0.014^{ns}	0.123*	0.012^{ns}	0.029
Lodging (%)	4.111^{ns}	452.111*	27.076^{ns}	132.01
Grain yield (kg ha^{-1})	43861.5^{ns}	7795672.7**	378030.4^{ns}	926732.3
AGB (t ha^{-1})	1.942^{ns}	43.089**	3.324^{ns}	4.097
Harvest index	0.0031^{ns}	0.00042^{ns}	0.0022^{ns}	0.0033

*Numbers in parenthesis = Degrees of freedom; ***=** Significant (P ≤ 0.05); ** = highly significant (p≤0.01) difference; NS= non significant; AGB= Above ground biomass; ha = Hectare

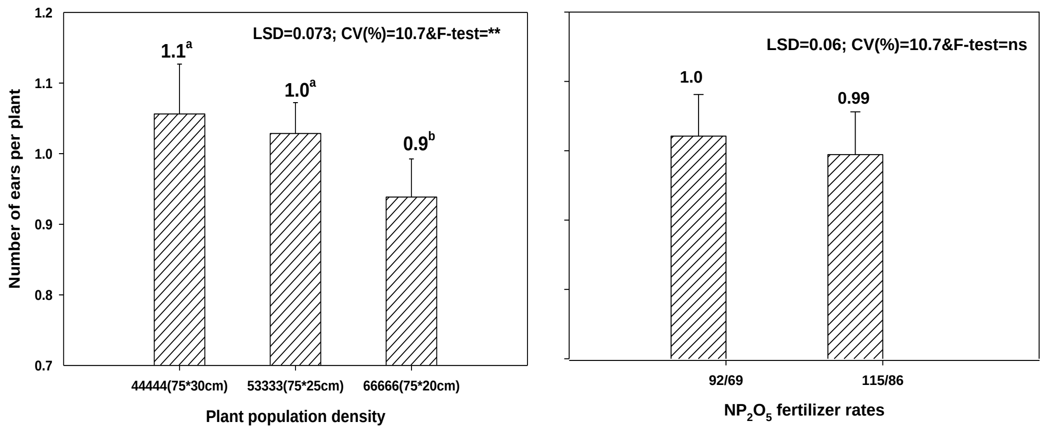
Plant height

Over location mean indicated the highest plant height 300.7cm was recorded from the plant population density of 66,666 plants ha^{-1} (75cm*20cm). While the lowest plant height was obtained at the plant population density of 53,333 plants ha^{-1}(75cm*25cm) but its effect was statistically at par with a plant population density of 44,444 plants ha^{-1} (75cm*30cm) (Table 3).

The highest plant height in closer Intra row spacing might be due to the presence of higher competition for sun light, crowding effect of the plant and other resources that decrease in the stem diameter and the number of green leaves. Earlier results explained that the number of plants increased in a given area, the competition among the plants for nutrients uptake and sunlight interception also increased [18]. This finding is in agreement with Hassan [19] who revealed that plant height increased with increasing plant density from 47600 to 71400 plants ha^{-1}.

Number of Ears per plant

Over locations mean indicated that the maximum number of ears per plant (1.1) was obtained from 44,444 plants ha^{-1} (75cm*30cm),while the minimum number of ears per plant (0.90) was recorded from the highest plant population density per hectare 66,666 (75cm*20cm) (Figure 1). The plant population density at 44,444 plants ha^{-1} increased 22.2% number of ears per plant over 66,666 plants ha^{-1}. The results indicate as plant population density increased the number of ear per plant decreased. At low plant population density, number plants limited the yield, while at high plant population density number of barren plants limited yield as well. This might be due to the efficient use of the crop to the nutrient applied per plant stand, and this which in turn had increased the nutrient availability for vigorous plant growth thus might have increased the number of ears plant^{-1}. These findings are in agreement with Hashemi-Dezfouli and Herbert [20] who reported a significantly higher number of ears per plant at lower plant density as compared to higher plant density.

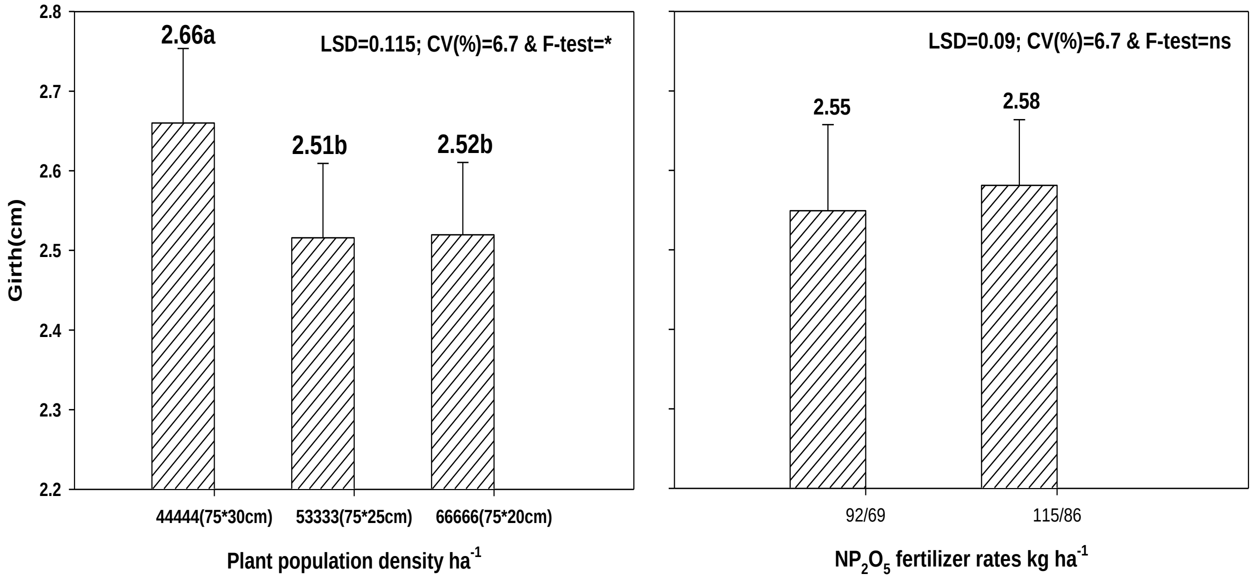


*LSD = Least Significant Difference; CV = Coefficient of Variation; Values followed by the same letter(s) within main treatment rates are not significantly different at 0.05 probability level.

Figure-1: Effect of Plant population density and NP fertilizer on number of ears per plant

Stem diameter (Girth)

Numerically the treatments having the plant population of 44,444 plants ha^{-1} (75x30cm) produced a maximum stem diameter of 2.66cm, while the minimum (2.51cm) was obtained by plant population density of 53,333 plants ha^{-1} (75x25cm) which was statistically at par with a plant population density of 66,666 plants ha^{-1} (75x20cm) (Figure 2). It means with decrease in plant population the plants obtained more soil moisture and nutrients than narrower-spaced plants and have more stem diameter as compared to high plant population. This is similar to the findings of Dalley et al. [21] and Azam et al. [22] who reported that wider-spaced maize plants obtained more soil moisture and nutrients than narrower plants and result in more stem girth development.



*LSD = Least Significant Difference; CV = Coefficient of Variation; Values followed by the same letter(s) within main treatment rates are not significantly different at 0.05 probability level.

Figure_2: Effect of Plant population density and NP fertilizer on stem diameter (girth)

Lodging percent

Maize variety BH-661 was sensitive to lodging, as its plant height goes higher up to 300.7 cm as indicated in table 3. Stalk lodging represents one of the most serious constraints to the use of high plant densities in late-maturing maize variety (BH661). Numerically, the highest lodging percent (36.5%) was recorded from the higher plant population density of 66,666 plants ha^{-1} (75*20cm) while, the minimum lodging percent (27.0%) was recorded from 44,444 plants ha^{-1} (75*30cm) (Table 3). The lodging percent was decreased by 26% at the plant population density of 44,444 plants ha^{-1} over 66,666 plants ha^{-1}. The obtained results indicate that as the plant population density increased the lodging also increased and vice versa. As the plant density increases the internodes become thinner, making the plant more prone to stalk lodging [23]. The stored carbohydrates in the maize stalks transported to grains and weakened the basal internodes, thus reducing the bending quality and providing an ease of lodging [24]; this is because the basal internodes act as a lever for holding the plants upright [25]. These results were in line with the result of Gou et al., [26], who reported more observed lodging at high plant population density as compared with lower densities.

Grain yield

As regards the response of grain yield to plant population density the presented data showed that the highest grain yield 7410 kg ha^{-1} was recorded from 75*20 cm (66,666 plants ha^{-1}). While, the lowest grain yield 6100 kg ha^{-1} was recorded from the lowest plant population density of 44,444 plants ha^{-1} which was not statistically significantly different from 53,333 plants ha^{-1} (Table 3). The data also showed that by planting 66,666 plants ha^{-1} was a 21.5% grain yield advantage over the lowest plant population density of 44,444 plant ha^{-1}. Such effect may be related to the increase of plant per meter square area and subsequently, increase the number of cobs harvested. Thus, balanced growth and development of plants need optimum plant population density because optimum density enables plants efficient utilization of available nutrients, soil water and better light interception coupled with other growth influencing factors.

This finding was in agreement with those obtained by Farnham [27] who reported that maize grain yield increased as plant density increased from 59,000 to 89,000 plant ha^{-1}.

Table_3: Over season and location main effect of fertilizer rate and plant population density on yield and yield components of maize at Jimma and Buno-Bedele zone during 2019 cropping season

Plant Population density ha^{-1}	**Over location**				
	Plant height (cm)	**Lodging (%)**	**Grain yield (kg ha^{-1})**	**AGB (kg ha^{-1})**	**HI**
66666(75*20cm)	300.7	36.5	7410	17060	0.42
53333(75*25cm)	291.1	34.7	6660	15660	0.41
44444 75*30cm)	294.3	27.0	6100	13970	0.42
LSD (0.05)	6.12	7.74	650	1360	0.04
F-test	**	*	**	**	NS
N/P_2O_5 (Kg ha^{-1})					
92/69	294.2	33.0	6750	15370	0.43
115/86	296.6	32.5	6700	15750	0.41
LSD (0.05)	4.99	6.32	530	1110	0.03
CV (%)	3.08	25.1	14.3	13.0	13.7
F-test	NS	NS	NS	NS	NS

LSD= Least significant difference; CV=Coefficient of variation; NS=Non-significant; HI= Harvest index; AGB=Above ground biomass; Values followed by the same letter within a column are not significantly different at P< 0.05.

Above-ground biomass yield

The highest above-ground biomass 17060 kg ha^{-1} was recorded from 75*20 cm (66,666 plant ha^{-1}), while, the lowest above-ground biomass 13970 kg ha^{-1}was recorded from the lowest plant population density of 44,444 plants ha^{-1} (Table 3). By planting 66,666plants ha^{-1} there was a 22% above ground biomass increase over plant population density of 44,444 plant ha^{-1}. This shows that an increase in plant population density increase above ground biomass yield because the plant per meter square area increase and consequently the number of cobs harvested. Biomass yield was decreased in wider spacing due to minimum plant height occurred and decreasing the ability of plants for capturing resources which were reflected as evident in their decreased biomass production. Thus an increase in biomass yield might have been on account of overall improvement in the vegetative growth of the plant due to optimum plants per unit area. These results were in agreement with Bullock et al. [28] who reported that narrow row spacing made more efficient use of available light and shaded the surface soil more completely during the early part of the growing season while the soil is still moist and therefore, narrow row spacing is more effective in producing biomass.

Harvest index

Harvest index is the ratio of grain yield to total above-ground biomass and the obtained result was in the acceptable range of 0.4 - 0.6 for maize [29].

Economic Analysis

The data presented in table 4 indicates that the highest net benefit (44,138 ETB ha^{-1}) was obtained from 66,666 plant ha^{-1}. Whereas, the lowest net benefit (36,955 ETB ha^{-1}) was obtained from 44,444 plants ha^{-1}. The same table also shows that planting 66,666 plants ha^{-1} increased the net benefit by 19.4% (7183 ETB ha^{-1}) as compared with 44,444 plants ha^{-1}.Concerning NP fertilizer application the highest net benefit was recorded from 92/69 kg ha^{-1} N/P_2O_5 fertilizer application and it increased the net benefit by 3% (1,214 ETB ha^{-1}).

Table_4: Partial budget analyses of NP fertilizer rates and plant population density on grain yield of late-maturing maize variety at Jimma and Buno-bedele zone during 2019 cropping season

Plant population Density ha^{-1}	GY (kg ha^{-1})	Adj.GY (kg ha^{-1})	GFB (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})
66,666(75*20cm)	7410	6669	46683	2545	44138
53,333(75*25cm)	6660	5994	41958	1983	39975
44,444 (75*30cm)	6100	5490	38430	1475	36955
N/P_2O_5 (Kg ha^{-1})					
92/69	6750	6075	42525	3631	38894

115/86	6700	6030	42210	4530	37680

*GY= Grain yield; GFB = Gross field benefit; TCV = Total cost that varied; NB = Net benefit;
ETB = Ethiopian Birr; Price of chemical fertilizer = 13.5birr kg^{-1}; Price of Urea = 10 birr kg^{-1}; Wage rate = 40 Birr man-day^{-1}; Retail price of grain = 7 birr kg^{-1}.

The farmers' perceptions were collected at the green ear stage and harvest period. Six maize stand evaluation criteria were set by farmers to decide optimal fertilizer recommendation and plant population per hectare for late-maturing maize variety (BH661). Accordingly, maize growth rate, probability of lodging, number of ears/plants and yield potential were found the most important for the maize stand evaluation criteria. Further, based on maize stand evaluation criteria that were set by farmers (Table 5) 23% of them chosen for 53,333 plants ha^{-1} (75*25cm) with that of 92/69 Kg ha^{-1} NP_2O_5 fertilizer rate.

Table_5: Farmers perception on optimal NP fertilizer application and plant population density on late maturing maize variety at Jimma and Buno-bedele zone during 2019 cropping

Farmers Evaluation Criteria	92/69 (Kg N/P_2O_5 ha^{-1})			115/86 (Kg N/P_2O_5 ha^{-1})		
	44,444 (75*30cm)	53,333 (75*25cm)	66,666 (75*20cm)	44,444 (75*30cm)	53,333 (75*25cm)	66,666 (75*20cm)
Weeding Frequency	High	Medium	Low	High	Medium	Low
Growth rate	Slow	Medium	Fast	Slow	Medium	Fast
Probability of lodging	Low	Medium	High	Low	Medium	High
Number of ears/plant	1	1	1	1	1	1
Cob size	Bigger	Medium	Smaller	Bigger	Medium	Smaller
Number of ear rotting	low	low	low	low	low	low
Yield potential	Lower	Medium	Higher	Lower	Medium	Higher
choice in Percentage	14%	23%	19%	11%	18%	15%

Conclusions and Recommendation

Declining soil fertility aggravated the challenge of agriculture to meet the world's increasing demand for food in a sustainable way and the variations in the morphology of the maize crop lead to different planting densities to reach maximum yield. Because of this, the study was conducted to validate the response of maize hybrid BH661 to different rates of NP fertilizer and plant population density at Jimma and BunoBedele zones, southwestern Ethiopia.

Accordingly, rigorous research efforts were made on farmer's fields of Jimma zone (Kersa and Omonada woredas) and Buno-Bedele zone in the vicinity of the Jimma Agricultural research center for three cropping seasons (2016-2018) and validation of the experiment was performed in 2019 main cropping season. The results revealed that the plant population density significantly improved grain yield and above ground biomass yield of the maize. The improvement was mainly due to the high plant population harvested ha^{-1} in higher plants ha^{-1} and vice versa.

The brief results from across sites indicate that grain and above-ground biomass yield of maize significantly affected by plant population density and not by different fertilizer doses. It can be concluded that the maximum grain yield (7410 kg ha^{-1}) and biomass yield (17060 kg ha^{-1}) was recorded with a plant population density of 66,666 plants ha^{-1} (75*20cm) which gave the highest net benefit 44,138.0 ETB. This result contradicted the previous recommendation of plant population density of 44,444 plant ha^{-1} (75*30cm). Therefore, the plant population density of 66,666 plant ha^{-1} (75 x 20cm a plant hill^{-1} or 75 x 40 cm two plants hill^{-1}) in complement with N/P_2O_5 fertilizer rate of 92/69 kg ha^{-1} can be recommended in the study area and similar agro-ecologies.

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