ISSN 2664-4010 (Print) & ISSN 2664-6730 (Online)
South Asian Research Journal of Agriculture and Fisheries
Abbreviated Key Title: South Asian Res J Agri Fish

| Volume-5 | Issue-6 | Nov-Dec -2023 | DOI: 10.36346/sarjaf.2023.v05i06.002

Original Research Article

Effect of Plant Density and NPS Fertilizer Rates on Growth, Yield and Yield Components of Maize (*Zea mays L.*) in Central highland of Ethiopia

Chala Chalchissa[1*], Mideksa Chala[1], Bahiru Addisu[1]
[1]Ethiopian Institute of Agricultural Research, Ambo Agricultural Research Center, Ambo, Ethiopia

***Corresponding Author:** Chala Chalchissa
Ethiopian Institute of Agricultural Research, Ambo Agricultural Research Center, Ambo, Ethiopia

Article History
Received: 09.08.2023
Accepted: 12.09.2023
Published: 20.12.2023

Abstract: Maize is an important cereal crop in Ethiopia due to its use as a source of food security. However, its productivity is limited by insufficient application of the NPS fertilizer and inappropriate plant density. A field experiment was conducted during 2020 and 2021 cropping seasons at Liban Jawi and Toke Kutaye districts of West Shoa Zone, Ethiopia to study the effect of plant density and NPS fertilizer rates on growth, yield, and yield components of maize. The experiment consisted of three plant populations (53,300, 66,600 and 88,800 plants ha^{-1}) and five NPS fertilizer rates (100, 150, 200, 250 and 300 kg NPS ha^{-1}) laid out in a randomized complete block design with three replications. The results showed that plant height, ear height and biological yield increased with increasing plant density. On the contrary ear length, number of grains per row, grain yield and harvest index decreased with increasing plant density. Plant density of 53,300 plants ha^{-1} produced the higher grain yield (5969 kgha^{-1}) compared to that of 88,800 plants ha^{-1} (5175 kg ha^{-1}). However, grain yield at 53,300 plants ha^{-1} did not show a significant difference with that of 66,600 plants ha^{-1} (5746 kg ha^{-1}). In case of NPS fertilizer rates the results showed that plant height, ear height, ear length, number of grains per row, 1000 seed weight, biological yield, grain yield and harvest index increased with increasing NPS fertilizer rates up to optimum rate. Fertilizer application of 200kg NPS ha^{-1} produced a higher grain yield (6710 kg ha^{-1}). The highest economic (126,423 Birr ha^{-1}) and a higher MRR (2630%) resulted from the application of 200 kg NPS ha^{-1} with a plant population of 53,300 plants ha^{-1}. Therefore a Plant density of 53,300 plants ha^{-1} and a blended fertilizer application with 200 kg NPS ha^{-1} was the most appropriate for highland maize in the study area.

Keywords: Plant density, NPS fertilizer rates, Maize and yield.

1. INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal grain crops used as the human diet, livestock feed and raw material for various industries in large parts of the world (Khan *et al*., 2008). Based on area and production in the world, maize is ranked as the third major cereal crop after wheat and rice (Food and Agriculture Organization of the United Nations [FAO], 2016). According to FAOSTAT (2013), 690.7 million tons of maize were produced on 135.4 million hectares worldwide, with an average yield of over 5.1 tons ha^{-1} in 2012. In Ethiopia maize has been selected as one of the high priority crops to feed the increasing population of the country. It is widely adapted to different agro-ecologies ranging from lowland to the highland areas of the country (Mosisa *et al*., 2001). The wider adaptability of the crop and the potential to produce more calories were important factors in considering maize as part of the national food security crop (Abate *et al*., 2015). In 2020/21 cropping season, it was cultivated with a total national production of 10.55 million tons from 2.5 million hectares with an average productivity of 4.2 ton ha^{-1} (CSA, 2021). In our country the average maize productivity is still 4.2 tons ha^{-1}(CSA, 2021) which is far below the world average 5.1 tons ha^{-1}. This yield gap in maize is attributed to various factors such as use of inappropriate agronomic practices (plant population density, planting dates, water management, unbalanced nutrient supply, limited use of inputs etc.), drought, declining of soil fertility, lack of credit facilities, poor seed quality, disease, insect pests and weeds (CIMMYT, 2004). From inappropriate agronomic practices plant population density and unbalanced nutrient supply are among the major limiting factors of maize production in the study area.

Plant population density per unit area is one of the important yield determinants of crops. It is an efficient management tool for maximizing grain yield by increasing the capture of solar radiation within the canopy (Monneveux *et al*., 2005). Optimum plant density ensures the plants to grow properly both in their aerial and underground parts through different utilization of solar radiation and nutrients. Yield can increase with increasing plant density up to an optimum level for a maize genotype grown under a set of particular environmental and management conditions and declines when plant density is increased further (Tollenaar *et al*., 1992).When the plant density exceeds an optimum level, competition among plants for light and nutrients become severe, consequently, the plant growth slows down and the grain yield decreases (Hasanuzzaman *et al*., 2009).

Besides plant population density unbalanced nutrient supplies are the most yield limiting factor in maize production. Fertilizers are an efficient exogenous source of plant nutrients (Akram *et al*., 2007). Plant growth and crop production require adequate and balanced supply of nutrients to maximize productivity by optimizing the plant nutrient uptake (Mengel and Kirkby, 2001). The fertilizer amount varies with soil type, fertility status, moisture amount, climatic variables, variety, crop rotation and crop management practices (Berihun & Woldegiorgis, 2012). The Ethiopian soils lack most of the macronutrients (mainly Nitrogen, Phosphorus and Sulfur) and micronutrients (Cu, B and Zn) because of long year's frequent cultivations of staple crops (EthioSIS, 2014 and Shiferaw, 2014). Recent studies have indicated that elements like N, P, K, S and Zn levels, as well as B and Cu are becoming depleted in most Ethiopian soils and deficiency symptoms are being observed on major crops in different areas of the country (ATA, 2013). The majority of maize growers depend on P in the form of Di-ammonium phosphate (DAP) and N in the form of urea (EthioSIS, 2014) which contain unbalanced nutrients. The application of unbalanced plant nutrients may aggravate the depletion of other important nutrient elements in soils. Increasing crop yields through the application of nitrogen and phosphorus alone can deplete other nutrients (FAO, 2000). According to (ATA, 2013) report soil of the study area is deficient in nitrogen, phosphorus and sulfur nutrients as indicated by Ethio-SIS map (Ethiopian Soil Information System). To alleviate the problem, the Ministry of Agriculture of Ethiopia has introduced a new brand of NPS blended fertilizer which contains N, P and S with the proportion of 19% N, 38% P_2O_5 and 7% S substituting DAP as source of P and S. This fertilizer has been currently distributed in Ethiopian crop production system (Ministry of Agriculture and Natural Resource [MoANR], 2013). Since the amount of P_2O_5 in the NPS is small as compared to the amount of P_2O_5 in the DAP it is necessary to add the rates of NPS fertilizer to get the required amount of balanced nutrients. New fertilizer materials (NPS) contain the necessary macro and micronutrients which would be required by the crops. Application of balanced fertilizers is the basis to produce more crop output from existing land under cultivation and nutrient needs of crops are according to their physiological requirements and expected yields (Ryan, 2008). Balanced fertilization guarantees optimal crop production, better quality product and benefits growers and is also the best solution for minimizing the risk of nutrient imbalances. The use of balanced fertilizers in deficient soils can improve fertilizer-use efficiency and crop profitability. Therefore, the objective of this study was to determine the optimum plant population and appropriate blended (NPS) fertilizer for growth, yield and yield components of highland maize at study area.

2. MATERIALS AND METHODS

2.1. Description of the study area

The field experiments were conducted under rain-fed conditions during the main cropping season for two consecutive years (2020 and 2021) at Liban Jawi and Toke kutaye districts in the West Shoa Zone, central highland of Ethiopia. Liban Jawi experimental site was geographically located at 8° 58‘ 41‘‘ N latitude and 37° 33‘ 37‘‘ E longitude with an average altitude of 2275 m a.s.l and the Toke Kutaye experimental site was geographically located at 8° 56‘ 60‘‘ N latitude and 37° 44‘ 55‘‘ E longitude with an altitude of 2052 m a.s.l. The soil texture of the experimental sites is clay. In the 2020 main cropping season, the mean maximum and minimum temperatures of the two districts during the season of the experiment were 25.6 and 11.8 °C, respectively, and the total annual rainfall was 1274.4 mm. In the 2021 main cropping season, the mean maximum and minimum temperatures of the two districts during the season of the experiment were 25.6 and 11.4 °C, respectively, and the total annual rainfall of 875.3 mm.

2.2. Description of experimental materials, treatments and design

The experiment was carried out by applying three plant population density (53,300, 66,600 and 88,800 plants ha-^{1}) and 5 levels of NPS fertilizer (100,150, 200, 250 and 300 kgha^{-1}) which were arranged in a randomized complete block design (RCBD) with three replications. The experimental plot size was measured 3m ×4.5m (13.5m^2) consisting of 6 rows of 0.75 m apart and 3m in length. The spacing between plots and replications were 0.5m and 1m respectively.

2.3. Experimental procedure and field management

The experimental field was ploughed by oxen, and land leveling was done manually before planting. Jibat maize variety was used as a test crop. Phosphorus fertilizer in the form of NPS was applied as per the treatments at planting and nitrogen fertilizer in the form of urea was applied at the rate of 200 kg ha-^{1} in two split application at knee height and before tasseling for all treatments. Two seeds were planted per holes on the 2nd weeks of May and thinned to one plant per stand. Hand weeding was carried out thrice. Harvesting was carried out manually at the middle of December when the foliage, stem and ear were fully dried from the net plot area for four inner most middle rows.

2.4. Soil sampling and analysis

The composite soil sample at 0-20 cm depth from the experimental field was taken before planting. The sample was air dried and ground to pass a 2mm sieve and necessary parameters such as soil texture, total Nitrogen, available P, pH, and OC were determined. For the determination of OC and N 1mm sieve was used. Soil texture was analyzed by Bouyoucos hydrometer method (Day, 1965). The total nitrogen content of soil samples was determined using the Kjeldahl procedure (Horneck *et al.*, 2011). Available P was extracted with a sodium bicarbonate solution following the procedure described by Olsen *et al.*, (1954). The pH of the soil was measured potentiometrically in the 1:2.5 soil: water mixture by using a pH meter and organic carbon was determined following Walkely and Black wet oxidation method (Walkely and Black, 1934).

2.5. Methods of data collection

Ten plants were selected randomly from each plot by excluding borders to collect growth, yield and yield contributing characters such as plant height, ear height, ear length, number of grains per row, above-ground biomass, grain yield and harvest index of the plant.

2.6. Statistical analysis

The collected data were statistically analyzed using the general linear model (GLM) procedures of the SAS statistical software (SAS Institute, 2000) to evaluate the effect of appropriate plant population density and NPS fertilizer application. Test of homogeneity of the data was applied and then a combined analysis of variance was performed over the two years by Bartlett's test (Bartlett, 1937). Duncan's multiple range tests (DMRT) were used to compare the treatment means at 5% of probability.

2.7 Economic analysis

For economic analysis, a simple partial budget analysis was employed using CIMMYT approach (CIMMT, 1988). For partial budget analysis, the factors with significant effect were considered. The yield was adjusted by subtracting 10% from average the gain yield. Then after, gross benefit was obtained by multiplying the adjusted yield by two years of harvesting months (December-January) average price of Ethiopian Birr 20 kg^{-1} for maize grain, Ethiopian Birr18.75kg^{-1} for maize seed and Birr 17.5kg^{-1} for NPS were taken for the economic analysis. Net benefit was calculated, by subtracting labor cost from gross yield. Finally, the marginal rate of return (MRR) was calculated. The mean market price of maize was obtained by assessing the market at harvest (2021 cropping season).

3. RESULTS AND DISCUSSION

3.1. Soil Physical and chemical characteristics of the study areas

The Physical and chemical properties of the soil were analyzed for the soil sample (0-20 cm depth) taken from the test field. The results of the analysis of the physical and chemical properties of the soil showed that the particle size distribution of sand, silt and clay were 32.4, 24, and 43.6% for Liban Jawi and 30.4, 24, and 45.6% for Toke Kutaye, respectively (Table 1). Based on soil textural triangle of the International Society of Soil Science (ISSS) system (Rowell, 1994), the textural classes of the soil of the two sites were clay. The texture shows the degree of weathering, nutrient and water retention capacity of the soil. The high clay content could indicate a high-water retention capacity of the soil in the study area. The soil in water pH (1:2.5) analysis result shows that the pH of the experimental sites were 6.17 and 5.88 for Liban Jawi and Toke Kutaye respectively (Table 1), which were rated as slightly acid and moderately acid according to Tekalign (1991). The organic carbon content of the soil for Liban Jawi and Toke Kutaye were 1.64 and 2.09 respectively, which are classified as moderate according to the rating of Tekalign (1991). The analysis result shows that the available P contents of Liban Jawi and Toke Kutaye sites were 9.41 and 10.14 (mg kg^{-1} soil), respectively (Table 1), which are rated as medium and high according to Cottenie (1980). Total nitrogen measures the total amount of nitrogen found in the soil, much of which is held in organic matter. The result of the analysis showed that the total nitrogen content were 0.16% and 0.17% for Liban Jawi and Toke Kutaye respectively. According to Tekalign (1991) total N availability classification, the total nitrogen of the experimental sites was rated as moderate. Therefore, the soil of the research sites has moderate total nitrogen content and requires nitrogen application, since the production potential of maize crop is strongly influenced by N.

Table 1: Initial soil chemical and physical characteristics at a depth of 0-20 cm layer of the soil before Planting of maize in 2020

Parameters								
Location	**p^H**	**OC**	**Total**	**Ava P**	**Sand**	**Silt**	**Clay**	**Textural**
	1:2.5	(%)	N (%)	(ppm)	(%)	(%)	(%)	Class
Liban Jawi	6.17	1.64	0.17	9.41	32.4	24	43.6	Clay
Toke Kutaye	5.88	2.09	0.16	10.14	30.4	24	45.6	Clay

Note: OC stands for organic carbon, N is for nitrogen and $AVaP_2O_5$ stands for total available phosphorus

Weather data

Table 2: Monthly Weather data of the study area (2020 and 2021)

	2020				**2021**			
	Total	Minimum	Maximum	Relative	Total	Minimum	Maximum	Relative
Month	Rain fall	temperature	temperature	humidity	Rain fall	temperature	temperature	humidity
	(mm)	(^{o}C)	(^{o}C)	(%)	(mm)	(^{o}C)	(^{o}C)	(%)
January	5.4	10.9	27	55.8	41.7	9.8	26.4	48.8
February	10.2	12.8	28.2	54.5	14.7	11.5	27	52.6
March	87.4	13.7	28.7	53.5	3.3	12.3	28.7	37.2
April	122.8	13.6	27.8	68.2	45.6	13.3	28.1	49.3
May	124.6	13.4	26.9	71.8	148.5	11.8	26.4	62.5
June	186.7	12.4	24.4	82.5	154.8	11.6	24.9	70.2
July	350.3	12.2	21.8	91	219.7	12.8	21.6	85.2
August	264.4	12.4	22.1	91.8	167.6	11.8	22.7	81.7
September	111.1	11.5	23.6	84.8	118.2	11.6	23.6	77.8
October	8.3	9.7	25.4	67.2	61.2	10.3	25.1	61
November	2.5	9.8	25.9	66.2	0	9.6	25.7	53.1
December	0.7	9.3	25.9	63	0	10	26.6	50.8
Total	1274.4				875.3			
Mean		11.8	25.6	70.8		11.4	25.6	60.9
Source: Ambo Agricultural Research Center's Meteorological Station (2020 and 2021)								

3.2. Analysis of variance

Analysis of variance (ANOVA) for the effect of plant density and NPS fertilizer rates for all maize parameters measured during the investigation indicated that, the effect of plant density on plant height, ear height, ear length, number of grains per row, biological yield, grain yield and harvest index was significant while the effect of Plant density on thousand seed weight was insignificant. The effect of NPS fertilizer rates on plant height, ear height, ear length, number of grains per row, biological yield, grain yield, thousand seed weight and harvest index was significant. Plant density and NPS fertilizer rates did not showed significant interaction ($P<0.05$) for all parameters.

3.3 Effect of plant density and fertilizer rates on growth, yield and yield components of maize

3.3.1 Plant height (cm)

The combined analysis of variance indicated that plant density and NPS fertilizer rates had significant effect ($P < 0.001$) on plant height of maize (Table 3). However, the interaction of plant density x NPS fertilizer rates was non-significant. The result revealed that the highest plant height (215cm) was recorded from higher plant density (88,800 plants ha^{-1}), whereas the lowest plant height (207 cm) was recorded from lower population density (53,300 plants ha^{-1}). The mean plant height increased with increasing plant density. The increased plant height at higher plant densities might be due to competition for light as a result of mutual shading effect. This result agreed with the findings of Hunduma and Tamirat (2022); Zeleke *et al.*, (2018); Imran *et al.*, (2015); Adeniyan (2014); Dawadi and Sah (2012) and Rafiq *et al.*, (2010), who reported that plant height increased with increasing planting density. In case of NPS fertilizer rates the maximum plant height (215 cm) was recorded from application of 300 kg NPS ha^{-1}, which were statistically at par with 200 and 250 kg NPS ha^{-1} with the plant height of (212 cm and 214 cm, respectively), whereas the minimum plant height (202 cm) was recorded from application of 100 kg NPS ha^{-1}. The mean plant height increased with increasing NPS fertilizer rates. The increased plant height at the highest level of blended NPS fertilizer rates could be attributed to the increasingly adequate supply of nitrogen, phosphorus and sulphur nutrients, which attributed to better vegetative development that resulted in increased mutual shading and inter nodal extension. This result agreed with the findings of Nure and Aman (2021) and Abera and Adinew (2020), who reported that application of NPS fertilizer up to 200kg ha^{-1} result in a significant increase in the plant height of Maize.

3.3.2. Ear height (cm)

The combined analysis of variance showed that ear height was significantly (P < 0.001) affected only by the main effect of plant density and NPS fertilizer rates (Table 3). The result revealed that the maximum ear height (107cm) was recorded from higher plant density (88,800 plants ha^{-1}), whereas the lowest ear height (100 cm) was recorded from lower plant density (53,300 plants ha^{-1}). The mean ear height increased with increasing plant density. The increased ear height at higher plant densities might be due to the crowding effect of the plant and higher intra-specific competition for resources. This result agreed with the finding of Hunduma and Tamirat (2022) and Zeleke *et al*., (2018), who reported that ear height increased with increasing plant population. In case of NPS fertilizer rates the maximum ear height (108 cm) was recorded from application of 300 kg NPS ha^{-1}, which was statistically at par with application of 200 and 250 kg NPS ha^{-1} while the minimum ear height (94 cm) was recorded from application of 100 kg NPS ha^{-1}. The mean ear height increased with increasing NPS fertilizer rates up to 200 kg NPS ha^{-1}. The increase in ear height could be due to an increase in cell elongation and increased vegetative growth due to different levels of nutrients that include NPS. This result disagreed with the finding of Kebede and Utta (2021), who reported that ear height was not influenced by the main effect of NPS fertilizer.

Table 3: Effect of plant density and NPS fertilizer rates on PH, EH, EL and NGPR of maize (Combined data over year and location during 2020 and 2021 cropping seasons)

	PH(cm)	EH(cm)	EL(cm)	NGPR
Population ha^{-1}				
53,300	207b	100c	19.1a	34.3a
66,600	208b	104b	17.6b	33b
88,800	215a	107a	16.7c	32.6b
LSD(0.05)	***	***	***	***
NPS Fertilizer rates ha^{-1}				
100 kg NPS ha-1	202c	94c	17.7b	32.4c
150 kg NPS ha-1	207b	103b	17.6b	33.2bc
200 kg NPS ha-1	212a	107a	18.7a	35.3a
250 kg NPS ha-1	214a	106ab	17.6b	33.5b
300 kg NPS ha-1	215a	108a	17.4b	32.2c
LSD(0.05)	***	***	**	***
CV (%)	4.3	8.3	6.8	6.5
PD*Fer	NS	NS	NS	NS
Where PH=Plant height, EH= Ear height, EL= Ear length, NGPR= No of grains per row, Means followed by same letter within a column are not significantly different by Duncan's Multiple				
Range test at 5% level of probability.				

3.3.3. Ear length (cm)

The combined analysis of variance indicated that plant density and NPS fertilizer rates had significant effect (P < 0.001) on ear length of maize (Table 3). However, interaction of plant density x NPS fertilizer rates was non-significant. The result revealed that highest ear length (19.1cm) was recorded from lower plant densities (53,300 plants ha^{-1}) whereas the shorter ear length (16.7 cm) was recorded from higher plant densities (88,800 plants ha^{-1}). The mean ear length reduced with increasing plant population. This might be because available nutrients, moisture, space and the light become limited in high plant population due to the high competition of soil resources between plants. This result agreed with results of Mandic *et al.,* (2016); Adeniyan (2014) and Shafi *et al.,* (2012) who reported that ear length decreased with increasing plant population. In case of NPS fertilizer rates, the maximum ear length (18.7 cm) was recorded from application of 200 kg NPS ha^{-1}, while the minimum ear length (17.4 cm) was recorded from application of 300 kg NPS ha^{-1}. Increasing NPS fertilizer level from 100 kg ha^{-1} to 200 kg ha^{-1} increased the ear length. This might be due to an increase in cell elongation and more vegetative growth attributed to crop requirements of the NPS blended fertilizer for its normal physiological growth. This result agreed with the finding of Orebo *et al.,* (2021), who reported that ear length increased with increasing blended fertilizer.

3.3.4. Number of grains per row

The combined analysis of variance indicated that plant density and NPS fertilizer rates had significant effect (P < 0.001) on number of grains per row of maize (Table 3). However, the interaction of plant density x NPS fertilizer rates was non-significant. The result revealed that the highest number of grains per row (34.3) was recorded from lower plant density (53,300 plants ha^{-1}), while the lowest number of grains per row (32.6) was recorded from higher plant density (88,800 plants ha^{-1}) which was statistically at par with plant density of (66,600 plants ha^{-1}). The mean number of grains per row decreased with increasing of plant density. The lowest number of grains per row at high plant density might be due to high competition for the resources such as light, moisture and fertilizer or due to less availability of nutrients to grain formation. This result agreed with the findings of Mandic *et al.,* (2016); Dawadi and Sah (2012) and Abuzar *et al* (2011) who reported that number of grains per row decreased with increasing planting density. In case of NPS fertilizer rates, the maximum number of grains per row (35.3) was recorded from application of 200 kg NPS ha^{-1}, whereas the minimum number of grain per row (32.2) was recorded from application of 300 kg NPS ha^{-1}which was at par with the application of 100 and 150 kg NPS ha^{-1}. The mean number of grains per row increased with increasing NPS fertilizer rates up to 200 kg NPS ha^{-1}. This is probably due to increased NPS level up to 200 kg NPS ha^{-1} levels might be ascribed to better uptake of all the nutrients and increased translocation of photosynthetic products from source to sink and increased photosynthetic assimilate production and its partitioning that might have favorable impacts on grains per row of maize.

3.3.5. Biological yield (kg ha^{-1})

The combined analysis of variance indicated that plant density and NPS fertilizer rates had significant effect ($P < 0.001$) on biological yield of maize (Table 4). However, the interaction of plant density x NPS fertilizer rates was non-significant. The result revealed that the highest biological yield (23825kg ha^{-1}) was recorded from higher plant density (88,800 plants ha^{-1}), while the lowest biological yield (17925kg ha^{-1}) was recorded from lower plant density (53,300 plants ha^{-1}). The mean biological yield increased with increasing in plant density. This result in line with Imran *et al.,* (2015), who reported that higher biological yields were obtained from higher planting density. In case of NPS fertilizer rates the maximum biological yield (23154kg ha^{-1}) was recorded from application of 250 kg NPS ha^{-1}, which was statistically at par with 300 kg NPS ha^{-1} with the biological yield (22664 kg ha^{-1}), while the minimum biological yield (17939 kg ha^{-1}) was recorded from application of 100 kg NPS ha^{-1} which was statistically at par with 150 kg NPS ha^{-1} with the biological yield (19039 kg ha^{-1}). The mean biological yield increased with increased NPS fertilizer rates up to 250 kg NPS ha^{-1} then after declined. Thus, an increase in the biomass yield up to 250 kg NPS ha^{-1} could be due to the general improvement in the vegetative growth of the plant through the application of NPS fertilizer in combination with optimum plant density. This result agreed with the finding of Abera and Adinew (2020), who reported that increasing the application of NPS fertilizer rates increased the biological yield of maize.

3.3.6. Grain yield (kg ha^{-1})

Grain yield is the main target of production. The combined analysis of variance indicated that plant density and NPS fertilizer rates had significant effect ($P < 0.001$) on grain yield of maize (Table 4). However, the interaction of plant density x NPS fertilizer rates was non-significant. The result revealed that the highest grain yield (5969 kg ha^{-1}) was recorded from a lower plant density (53,300 plants ha^{-1}) which was statistically at par with a plant density of (66,600 plants ha^{-1}) with a grain yield of (5746 kg ha^{-1}), whereas the lowest grain yield (5175kg ha^{-1}) was recorded from higher plant density (88,800 plants ha^{-1}). The mean grain yield decreased with increasing the plant density. The higher grain yield at optimum planting densities might be due to the availability of more nutrients which led to more growth and higher assimilates translocation to grains. This result disagreed with the findings of Adeniyan (2014) and Rafiq *et al*., (2010), who reported that grain yield of maize increased with increasing plant density of 53,300 plants ha^{-1} to 99,900 plants ha^{-1}. In case of NPS fertilizer rates the maximum grain yield (6710 kg ha^{-1}) was recorded from application of 200 kg NPS ha^{-1}, whereas the minimum grain yield (4932 kg ha^{-1}) was recorded from application of 100 kg NPS ha^{-1}. Which was statistically at par with application of 300 kg NPS ha^{-1} with grain yield of (5384 kg ha^{-1}). The mean grain yield increased with increased NPS fertilizer rates up to 200 kg NPS ha^{-1}. This might be because of the fact that phosphate application as being particularly useful in promoting a good root system, which could favor the best utilization of mineral nutrients from the soil. This result agreed with the finding of Abera and Adinew (2020), who reported that increased application of NPS fertilizer up to 200kg NPS ha^{-1} increases grain yield of maize.

Table 4: Effect of plant density and NPS fertilizer rates on biological yield, grain yield, 1000 seed weight and harvest index of maize (Combined data over 2020 and 2021 cropping season)

	BY(kg ha^{-1})	GY(kg ha^{-1})	TSW(g)	HI (%)
Population ha^{-1}				
53,300	17925c	5969a	273a	34.3a
66,600	20065b	5746a	274a	28.7b
88,800	23825a	5175b	267a	22.8c
LSD(0.05)	***	***	NS	***
NPS Fer rates ha^{-1}				
100 kg NPS ha^{-1}	17939c	4932c	263b	28.7b
150 kg NPS ha^{-1}	19039bc	5380b	269b	29.9b
200 kg NPS ha^{-1}	20228b	6710a	271b	32a
250 kg NPS ha^{-1}	23154a	5742b	283a	26.2c
300 kg NPS ha^{-1}	22664a	5384c	271b	26.2c
LSD(0.05)	***	***	**	***

	BY(kg ha^{-1})	GY(kg ha^{-1})	TSW(g)	HI (%)
CV (%)	14.3	13.2	8.4	14.8
PD*Fer	NS	NS	NS	NS
Where, BY= Biomass yield, GY= Grain yield, TSW= 1000 seed weight and HI=Harvest index, Means followed by same letter within a column are not significantly different by Duncan's Multiple Range test at 5% level of probability.				

3.3.7. Thousand grain weight (g)

Grain weight is an important component of the yield that is very helpful in estimating the grain yield. The combined analysis of variance indicated that thousand grain weight was significantly ($P < 0.01$) affected only by the main effect of NPS fertilizer rates (Table 4). The result revealed that the higher thousand grain weight (283g) was recorded from application of 250 kg NPS ha^{-1}, whereas the lower thousand seed weight (263g) was recorded from application of 100 kg NPS ha^{-1}, which was statistically at par with 150, 200 and 300 kg NPS ha^{-1}. The mean thousand seed weight increased with increased NPS fertilizer rates up to 250 kg NPS ha^{-1}. This might be due to the greater contribution of NPS fertilizer by producing healthy kernels i.e., well-filled kernels and bigger kernels. This result agreed with the finding of Nure and Jara (2021), who reported that an increase in the NPS rate from 0 kg NPS ha^{-1} to 200 kg NPS ha^{-1} significantly increased the thousand grain weight.

3.3.8. Harvest Index (%)

The harvest index indicates the physiological efficiency and ability of a culture to convert total dry matter into an economic yield. The combined analysis of variance showed that plant density and NPS fertilizer rates had significant effect ($P < 0.001$) on harvest index of maize (Table 4). However, the interaction of plant population x NPS fertilizer rates was non-significant. The result revealed that the highest harvest index (34.3%) was recorded from lower plant density (53,300 plants ha^{-1}), while the lowest harvest index (22.8%) was recorded from higher plant population (88,800 plants ha^{-1}). The mean harvest index decreased with increasing plant population. This result disagreed with the result of Shafi *et al*., (2012), who reported that the harvest index increased with increasing plant population. Regarding NPS fertilizer rates the maximum harvest index (32%) was recorded from application of 200 kg NPS ha^{-1}, whereas the minimum harvest index (26.2%) was recorded from application of 250 kg NPS ha^{-1}, which was statistically at par with 300 kg NPS ha^{-1}. The mean harvest index increased with increasing NPS fertilizer rates up to 200 kg NPS ha^{-1}. The increment in harvest index at higher rates of blended might be attributed to greater photo assimilate production and its ultimate partitioning into grain yield. This result agreed with the findings of Nure and Jara (2021) and Abera and Adinew (2020), who reported that increased application of NPS fertilizer up to 200kg NPS ha^{-1} increases harvest index of maize.

4. Economic Analysis

The price of inorganic fertilizer and Maize seeds increases from time to time, therefore, optimizing fertilizer rate and plant density to maximize yields and economic return is very crucial. The economically optimum fertilizer rate and plant density can be found when the margin between the values of fertilizer, the seed produced, and production cost is maximized. The economic analysis indicated that the plant population of 53,300 plants ha^{-1} with the application of 200 kg ha^{-1} NPS was appropriate since it gave the highest net benefit (Table 5). The highest net benefit (126423 EB/ha) was obtained when 53,300 plants ha^{-1} with the application of 200 kg ha^{-1} NPS. On the other hand, the highest marginal rate of return (MRR) (2630%) was obtained from the treatment of 200 kg ha^{-1} NPS with 53,300 plants ha^{-1}. An increased plant density and NPS fertilizer rate increased the costs of products directly through increased fertilizer cost, seed cost, seed treatments, and crop management.

Table 5: Marginal analysis of maize yield as influenced by plant population and blended NPS fertilizer rate

Treatments		Grain Yield	Adjusted Grain	Gross net	Total Variable	Net Benefit	MRR
Plant density ha^{-1}	NPS (kg ha^{-1})	(Kg ha^{-1})	Yield (Kg ha^{-1})	Benefit (EB ha^{-1})	Cost (EB ha^{-1})	(EB ha^{-1})	(%)
53,300	100	5037	4533	90666	2219	88447	
66,600	100	5186	4667	93348	2331	91017	2284
88,800	100	4573	4116	82314	2538	79777	D
53,300	150	5917	5325	106506	3094	103412	1626
66,600	150	5379	4841	96822	3206	93616	D
88,800	150	4845	4361	87210	3413	83798	D
53,300	200	7244	6520	130392	3969	126423	2630
66,600	200	6860	6174	123480	4081	119399	D
88,800	200	6025	5423	108450	4288	104163	D
53,300	250	5996	5396	107928	4844	103084	D

Treatments		**Grain Yield**	**Adjusted Grain**	**Gross net**	**Total Variable**	**Net Benefit**	**MRR**
Plant density ha^{-1}	NPS ($kg\ ha^{-1}$)	($Kg\ ha^{-1}$)	Yield ($Kg\ ha^{-1}$)	Benefit ($EB\ ha^{-1}$)	Cost ($EB\ ha^{-1}$)	($EB\ ha^{-1}$)	(%)
66,600	250	5792	5213	104256	4956	99300	D
88,800	250	5439	4895	97902	5163	92740	D
53,300	300	5650	5085	101700	5719	95981	D
66,600	300	5511	4960	99198	5831	93367	D
88,800	300	4991	4492	89838	6038	83801	D
Cost of maize grain 1kg=20.00, Cost of maize seed 1kg=18.75 and Cost of NPS fertilizer 1kg NPS= 17.5							

5. CONCLUSIONS AND RECOMMENDATION

Results of the study showed that the highland maize responded positively to plant population and NPS fertilizer rates. Plant population of 53,300 plants ha^{-1} produced the highest grain yield while application of blended NPS fertilizer at the rate of 200 kg ha^{-1} produced the highest grain yield of maize. Plant population of 53,300 plants ha^{-1} with the spacing of 75 cm x 25 cm was suitable for the higher yield of highland maize in central highland of Ethiopia. Although, higher rates of NPS 200 kg ha^{-1} increased the yield of highland maize and application of blended NPS fertilizer at the rate of 200kgha^{-1} was appropriate dose and economical for highland maize cultivation in central highland of Ethiopia. Therefore, a plant population of 53,300 plants ha^{-1} with the application 200 kg ha^{-1} NPS was recommended for maize in central highland of Ethiopia.

REFERENCES

- Abate, T., Shiferaw, B., Menkir, A., Wegary, D., Kebede, Y., Tesfaye, K., Kassie, M., Bogale, G., Tadesse, B., & Keno, T. (2015). Factors that transformed maize productivity in Ethiopia. *Food security*, *7*(5), 965-981.
- Abera, T., & Adinew, A. (2020). Effect of blended NPS fertilizer supplemented with nitrogen on yield components and yield of maize (Zea mays L.) in Kachabirra district, Kembata Tambaro zone, southern Ethiopia. *International Journal of Research in Agricultural Sciences*, *7*, 2348-3997.
- Abuzar, M. R., Sadozai, G. U., Baloch, M. S., Baloch, A. A., Shah, I. H., Javaid, T., & Hussain, N. (2011). Effect of plant population densities on yield of maize. *The Journal of Animal & Plant Sciences*, *21*(4), 692-695.
- Adeniyan, O. N. (2014). Effect of different population densities and fertilizer rates on the performance of different maize varieties in two rain forest agro ecosystems of South West Nigeria. *African Journal of Plant Science*, *8*(8), 410-415.
- Akram, A., Fatima, M., Ali, S., Jilani, G., Asghar, R. (2007). Growth, yield and nutrients uptake of sorghum in response to integrated phosphorus and potassium management. *Pak J Bot*, 39(4), 1083-1087.
- ATA (Agricultural Transformation Agency). (2013). Status of soil resources in Ethiopia and priorities for sustainable management. Ethiopian agricultural transformation agency In: Global Soil partnership (GSP) for eastern and southern Africa. March 25-27: 2013, Nairobi, Kenya.
- Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Society of London. Series A-Mathematical and Physical Sciences*, *160*(901), 268-282.
- Berihun, B., & Woldegiorgis, G. (2012). Potato research and development in Ethiopia: Achievements and trends. Proceedings of the national workshop on seed potato tuber production and dissemination (pp. 35–44). Bahir Dar, Ethiopia.
- CIMMYT (International Maize and Wheat Improvement Center), 2004. Second Semi-Annual control treatments on growth, yield, Yield attributes, some seed technological characters of maize plants and its associated weeds. *J Agric Sci Mansoura Univ*, 31(7), 4259-4270.
- CIMMYT (International Maize and Wheat Improvement Center). (1988). Partial budget analysis for mean grain yield.
- Cottenie, A. (1980). Soil and plant testing as a basis of fertilizer recommendations. FAO soil bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome.
- CSA (Central statistical authority). (2021). The federal democratic republic of Ethiopia central statistical agency. Agricultural sample survey 2020/21, Volume I. Report on area and production for major crops (private peasant holdings main season). Statistical Bulletin 590, Addis Ababa, Ethiopia. Pp. 1-139.
- Dawadi, D. R., & Sah, S. K. (2012). Growth and yield of hybrid maize (Zea mays L.) in relation to planting density and nitrogen levels during winter season in Nepal, 23(3) 218 - 227.
- Day, P. R. (1965). Hydrometer method of particle size analysis. In C. A. Black (Ed.), Methods of soil analysis: American society of agronomy no. 9. Part 2 (pp. 562– 563). Wisconsin Argon.
- EthioSIS (Ethiopian Soil Information System). (2014). Soil analysis report. Agricultural Transformation Agency (Unpublished).
- FAO (Food and Agriculture Organization of the United Nations). (2016). Food and agriculture data, Italy, Rome. Online. FAO. Retrieved October 14, 2019, from http://www.fao.org/faostat/en/#data/QC/visualize
- FAO (Food and Agriculture Organization). (2000). Fertilizers and their use. International Fertilizer Industry Association. Food and Agriculture Organization of the United Nations Rome, Italy.

- FAOSTAT. (2013). Food and Agriculture Organization Statistics). 2013. Food and Agriculture Organization Statistics Data Base, Agricultural production indices. Roma, Italy. DOI:http://www.faostat3.foa.org/download /O/QC/E (Accessed on 20 July 2015.
- Hasanuzzaman, M., Rahman, M. L., Roy, T. S., Ahmed, J. U., & Zobaer, A. S. M. (2009). Pant characters, yield components and yield of late transplanted Aman Rice as Affected by plant spacing and number of seedling per hill. *Advances in Biological Research*, *3*(5-6), 201-207.
- Horneck, D. A., Sullivan, D. M., Owen, J. S., & Hart, J. M. (2011). Soil test interpretation guide. EC: Oregon State University.
- Imran, S., Arif, M., Khan, A., Khan, M.A., Shah, W., & Latif, A. (2015). Effect of nitrogen levels and plant population on yield and yield components of maize. *Advances in Crop Science and Technology*, pp.1-7.
- Kebede, M. B., & Utta, H. Z. (2021). Effects of Applying Blended Mineral NPS and Nitrogen Fertilizers on Growth, Yield Components, and Yield of Maize (Zea mays L.) in Fedis District, Eastern Ethiopia. *East African Journal of Sciences*, *15*(2), 167-182.
- Khan, H. Z., Malik, M. A., & Saleem, M. F. (2008). Effect of rate and source of organic material on the production potential of spring maize (Zea mays L.). *Pak J Agric Sci*, *45*(1), 40-43.
- Mandic, V., Bijelic, Z., Krnjaja, V., Tomic, Z., Stanojkovic-Sebic, A., Stanojkovic, A., & Caro Petrovic, V. (2016). The effect of crop density on maize grain yield. *Biotechnology in Animal Husbandry*, *32*(1), 83-90.
- Menge,l K., & Kirkby E. A. (2001). Principles of Plant Nutrition, 5th ed. Kluwer Academic publishers: dordrecht, the Netherlands, pp. 481–509.
- MoANR (Ministry of Agriculture and Natural Resource of Ethiopia). (2013). Transitioning into the implementation of soil test based fertilizer use system in Ethiopia. Available at: WWW.goa.gov.et/ documents/.
- Monneveux, P., Zaidi, P. H., & Sanchez C. (2005). Population density and low nitrogen affects yield. Associated Traits in Tropical Maize. *Crop Sci*, *45*(2), 103-106.
- Worku, M., Jemal, A., Leta, T., Haji, T., Legesse, W., Kassa, Y., ... & Habtamu, Z. (2001). Development of improved maize germ plasm for the mid and low altitude sub humid agro ecologies of Ethiopia. In: Enhancing the Contribution of Maize to Food Security in Ethiopia: Proceedings of the second national maize workshop of Ethiopia: CIMMYT (International Maize and Wheat Improvement Center) and EARO (Ethiopian Agricultural Research Organization), 27-30.
- Nure, A., & Jara, H. A. (2021). Evaluation of Blended NPS Fertilizer Rates and Inter Row Spacing on Yield Components and Yield of Maize (Zea Mays L.). *Iraqi Journal of Industrial Research*, *8*(3), 79-99.
- Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular, 939, 1-19.
- Orebo, D., Shanka, D., & Hadaro, M. (2021). Maize (Zea mays L.) yield response to the effect of blended fertilizer and varieties under supplemental irrigation at Hadero Zuria Kebele, southern Ethiopia. *Heliyon*, *7*(8), e07697.
- Rafiq, M. A., Ali, A., Malik, M. A., & Hussain, M. (2010). Effect of fertilizer levels and plant densities on yield and protein contents of autumn planted maize. *Pak J Agri Sci*, *47*(3), 201-208.
- Rowell, D. L. (1994). Soil science: Method and applications. Routledge, UK. Pp. 360.
- Ryan, J. (2008). A Perspective on balanced fertilization in the Mediterranean Region. *Turky journal of Agriculture*, 32, 79-89.
- Sakatu H., & Mabirate, T. (2022). Effect of Population Density and Fertilizer Rates on Yield and Yield Components of High Land Maize. *Journal of Natural Sciences Research*, *13*(3), 26-30.
- SAS Institute. (2000). SAS User's Guide, Statistics version 8.2 ed. SAS Inst., Cary, NC, USA.
- Shafi, M., Bakht, J., Ali, S., Khan, H., Khan, M. A., & Sharif, M. (2012). Effect of planting density on phenology, growth and yield of maize (Zea mays L.). *Pak J Bot*, *44*(2), 691-696.
- Shiferaw, H. (2014). Digital soil mapping: Soil fertility status and fertilizer recommendation for Ethiopian agricultural land. Conference paper. Addis Ababa, Ethiopia.
- Tekalign, T. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.
- Tollenaar, M. (1992). Is low plant density a stress in maize? *Maydica*, 37, 305-311.
- Walkley, A., & Black, A. (1934). An examination of Degtjareff Method for Determine Soil Organic Matter and Proposed Modification of the Chromic Acid Titration Method. *Soil Science*, 37, 29-38.
- Zeleke, A., Alemayehu, G., & Yihenew, G. S. (2018). Effects of planting density and nitrogen fertilizer rate on yield and yield related traits of maize (Zea mays, L.) in Northwestern, Ethiopia. *Adv Crop Sci Tech*, *6*(2), 1-5.