7. Maize Yield-Limiting Nutrients under Variable Locations in Major Maize Growing Areas of North West Ethiopia

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Abstract

Globally, crop production is affected by soil nutrient deficiency. The application of nutrients is desirable to a given crop, soil type, and agroecology under changing climates. Thus, this experiment was initiated to investigate the yield-limiting nutrients through a nutrient omission trial on maize in the 2020/2021 cropping season in North West Ethiopia. It was arranged in a randomized complete block design with three replications. The treatments were compriosed of N, P, K, S, B, and Zn omitted treatments. Besides, NPKSZnB (All), recommended NP, no fertilizer, and RNP+S_1

0.001) affected grain yield. The highest grain yield (9.2tha^{-1}) was achieved by applying NPKSZnB nutrients, while the omission of K, S, Zn and B nutrients had no discernible effect. The lowest grain yield of 1.3tha^{-1} was recorded from treatment with no fertilizer followed by N omitted treatment (1.4tha^{-1}). The omission of N and P nutrients provided significantly lower grain yield as compared to the treatments receiving all the nutrients. Without N treatment decreased, grain yield by 55%, followed by the absence of P, which decreased grain yield by 25%, while the absence of K,S,Zn,B had no statistically significant impact on grain yield as compared to NP nutrients alone. Therefore, N and P nutrients are the most yield-limiting nutrients in Ethiopian soils. Overall, this finding showed that Nitrogen and Phosphorus were the most important nutrients to boost the yield of maize. So, optimizing the rate of yield-limiting nutrients are required for judicious use of fertilizers in the study areas and similar agroecological zones of Ethiopia. It is suggested to conduct timely assessment of indigenous soil supplying capacity of KS and micronutrients in agricultural soils.

Keywords*: Omission, Nitrogen, Nutrients, Phosphorus, Productivity, Yield.*

Introduction

Agriculture contributes about 50 % to the annual gross domestic product in Ethiopia (Tamene *et al*., 2017). The cereal crops production is covered large proportion in areas and production which is about 81%, and 88%, respectively (CSA, 2021). The share of imported fertilizer inputs used by major cereal crops mainly tef, maize, and wheat is 60% (Mesfin, 2009). The agriculture development led industrialization economic policy brought about dramatic progress in agriculture with an annual growth rate of over 8% (ADLI, 2001). The main goal of this strategy is to increase the use of agricultural inputs including improved seeds, fertilizers, and pesticides. Thus, fertilizer use has shown a linear increase from below 37 metric metric tons in 1985 jumped to over 134 metric metric tons at the end of 1994.

Currently, the country imports about 1.4 million metric metric tons of multi-nutrient fertilizers and is projected to use over 2 million metric metric tons at the end of 2025. However, a steady increase in yields in crop yield has been shown with the application of an imported high dose of fertilizers. The declining returns of fertilizers in Ethiopia could be the use of a low proportion of the most limiting nutrients such as Nitrogen and Phosphorus. For over 35 years, the proportion of imported Nitrogen in the fertilizer system of the country is 15 %, whereas between 2000 and 2015 it increased to 35 % (IFDC, 2012). However, contrary to the experience of Ethiopia, reports from other countries show that Nitrogen is the leading nutrient in global agriculture followed by Phosphorus and Potassium (Heffer *et al*., 2017; Yara, 2018; Sinha and Tandon, 2020).

Research reports on responses of N and P fertilizers by major crops (tef, maize, and wheat,) in Ethiopia accounted for over 75 % of the crop production and fertilizer consumption (Rashid *et al*., 2014). However, it lacks right ratio between the fertilizer imported and used concerning the demand for NP nutrients in the crop production system of the country. There are also different factors affecting the response of crops to fertilizers; these may include poor targeting of the right fertilizers in the right places (Tamene *et al*., 2017). In Ethiopia, fertilize is not applied by considering site and crop type in previous decades. Thus, the 4Rs principles (right fertilizers, right methods, right time, and right rate) in the use of multi-nutrient fertilizers are important guidlines to exploit the potential of fertilizers (Johnsmetric metric ton and Bruulsema, 2014; Bruulsema *et al*., 2019; IFA, 2020). Cognizant of this fact, the EthioSIS projecthas mapped the soil nutrient status of agricultural lands in the country (EthioSIS, 2016). EthioSIS project identified many essential nutrients that are deficient and critically required by the agricultural soils of the country. The deficient nutrients include N, P, K, S, B, Zn, Fe, and Cu. However, the Map developed by EthioSIS was not validated under field conditions. Yield response is used to assess the capacity of the soil to supply nutrients (Xu *et al*., 2014). The application of proper nutrients in specific soils could reduce the risks and uncertainties associated with agricultural crop productivity (Tijjani *et al*., 2022) and increase the potential to achieve the attainable yield. The objective of this experiment was to investigate the most maize yield limiting nutrients in Nitisols of North West Amhara, Ethiopia.

Materials and Methods

Study Site Characteristics: The omission trials to identify yield-limiting nutrients were implemented in Jabitahnan, Burie, Womberma, Ayehu Guagusa, south Achefer, and Mecha in the Amhara region, Ethiopia. Jabitahnan, Burie, Womberma, South Achefer, and Mecha, districts are parts of the West Gojjam administration zone of the Amhara National Regional State whereas Ayehu Guagusa district is found in the Awi administration zone. These districts are the predominantly maize-growing belts of Amhara region, north western part of Ethiopia. About 23 on farm experimental sites where each district received 2 to 5 sites were chosen.

Experimental fields were selected considering the dominant soil types, different cropping systems, and farm management practices with a range of socioeconomic settings. Nitisols are the dominant soil type in study areas. Cereal-based cropping system is the dominant type of cropping system in the study areas. Maize, Tef, wheat, and finger millet are the major cereal crops grown in the study areas. Noug (*Guizotia abyssinica Cas*s) crop also produced as oil sources for farmers.

Descriptions of Experimental Sites Selected Soil Chemical Properties: The state of soil chemical properties before planting varied between sites (Table 2). The selected soil properties of multi-location experimental sites varied due to the intrinsic nature of soils and management. Soil pH (H_2O exhibited wide variability with mean value ranging from 5.1 to 5.6. The maximum and minimum pH value recorded in the study areas are 4.7 and 6.0, respectively. The lower pH (H_2O) values were observed in Womberma, Jabitehnan, Mecha, and South Achefer districts.The highest Phosphorus value (19 $mgKg^{-1}$) is observed in one of the sites found in the Koga irrigation command area at Mecha District. The available Phosphorus is found between 2.9 to 19.0 $mgKg^{-1}$. All experimental sites, except the Engutie trial site in the Mecha district, had a mean available

Phosphorus far below the critical value. The higher soil Phosphorus in the soil might be associated with the frequent application of phosphate fertilizers in the double cropping seasons at Koga irrigation site in Mecha district. The cation exchange capacity ranged from 26.6 to 33.9 Meq/100g soil. Total Nitrogen content ranged from 0.10-0.22 % in soils of the study area. The total Nitrogen content varied from site-to-site experimental locations. The total Nitrogen of study soils ranged from medium to high based on Tekalign *et al*., (1991) ratings. This is associated with the mining of native soil nutrients in the farming system as a result of the complete removal of crop residue and livestock feed. The organic carbon content of the soil was found between 1.8 and 3.2 % with a range of low to medium organic carbon for Ethiopian soils as per criteria developed by (Tekalign *et al*., 1991).

Table1. Selected soil physic-chemical properties during planting across study sites

Soil paramet rs	Statistics	Locations						Critical value	Rating	Reference
		Ayehu Guagusa [4]	Bure [2]*	Jabitehnan [4]	Mecha [4]	S. Acheffer [5]	Wombema [5]			
pH (H_2O)	Mean	5.4	5.2	5.2	5.1	5.4	5.6	5.5	Strong to moderately acidic	(Tekalign *et al*., 1991)
	Min	5.1	5.2	4.8	4.9	4.9	4.7			
	Max	5.8	5.3	5.8	5.3	6.0	5.6			
	Mean	8.0	6.6	7.9	7.8	4.7	7.8	10.0	Low to high	(Tekalign *et al*., 1991)
	Min	7.1	6.0	5.1	2.9	3.9	3.8			
	Max	9.7	7.1	14.0	19.0	5.7	11.0			
	Mean	34.7	29.4	28.1	28.2	30.3	30.2	-	Medium to very high	FAO (2006)
	Min	28.2	27.5	20.7	25.0	23.2	26.6			
	Max	42.8	31.9	38.6	31.6	36.9	34.1			
OC (%)	Mean	2.6	2.6	2.0	1.8	2.3	2.6	2.0	Low to medium	(Tekalign *et al*., 1991)
	Min	2.2	2.2	1.9	1.8	1.8	2.1			
	Max	3.2	2.8	2.2	1.9	2.6	3.1			
TN (%)	Mean	0.16	0.13	0.13	0.14	0.15	0.18	0.2	Medium to high	(Tekalign *et al*., 1991)
	Min	0.10	0.10	0.10	0.10	0.10	0.20			
	Max	0.20	0.22	0.20	0.18	0.16	0.22			

** Numbers in the parenthesis are No. of sites, CEC: cation exchange capacity, Min; minimum, Max: maximum, OC: organic carbon, P: available Phosphorus, TN: total Nitrogen*

Research Design: This experiment was conducted on a total of 23 sites across six districts. The experiment was arranged in a randomized complete block design and replicated three times at each farmer field. The nutrient omission experiment consisted of ten treatments including a no fertilizer (All omitted), All (NPKSZnB), All-S (S omitted), All-K (K omitted), All-Zn (Zn omitted), All-B (B omitted), All-P (P omitted), All-N (N omitted) and recommended NP (KSZnB omitted). Another NP treatment (NPS_1) with the additional of Sulphur nutrients with a 30 $Kgha^{-1}$ was used to further evaluate Sulphur fertilizer with a higher amount.

The rate for Nitrogen, Phosphorus, Potassium, Zinc, and Boron were 138, 92, 60, 5, and 1 $Kgha^{-1}$, respectively at all experimental sites. The rate of Sulphur was 10.5 and 30 $Kgha^{-1}$ for S and $S_{1,}$ respectively. The second rate of S, 30 $Kgha^{-1}$ was used to exhaustively see the effects of S on maize yield in the farming system.

Sources of Nitrogen, Phosphorus, Potassium, Sulphur, Zinc, and Boron were urea (46-0-0), triple super phosphate (0-46-0), Potassium chloride (0-0-60), magnesium sulfate (28% SO_3^-), EDTA Zinc (12 % Zn), and borax (11 % B), respectively. Recently released early maturing maize variety BH-546 was used in the Mecha district whereas late-maturing maize variety BH 660 was used for the other all districts.

Trial Management: Soil and crop management practices were done following research recommendations. After preparing the fields, all the sites were planted from 5 June to 30 June 2021. An average maize plant stands of 44444 per hectare was reached by sowing two seeds in each hole at intervals of 0.3 m in 0.75 row spacing, which were then thinned to one plant per hill. All fertilizers were applied by band application at planting except Nitrogen. Three equal split applications of Nitrogen were done: at planting, 35 days following emergence, and 65 days after emergence. Weed management was started after 2 weeks after planting. Each site has been weeded three times.

Data Collections: One composite soil sample of 0-20 cm was collected from each trial site to determine the status of soil fertility before planting. Major soil properties such as soil pH-H_2O, organic carbon (OC), available Phosphorus (AP), exchangeable acidity, and total Nitrogen (TN) analysis were conducted in Adet Agricultural Research Center's soil laboratory.

Maize was harvested from a net plot of 9 m^2 (36 plants), that is, constituting the 4 middle rows in each plot, leaving 0.75 m as border on each side of the row.

Above Ground Biomass: all plants in the net plots were harvested and the total fresh weights of cobs and stover were measured at the field using digital balance and then converted into $Kgha^{-1}$.

Grain Yield: all cobs were taken for drying. It was dried by air to constant weight and converted to $Kgha^{-1}$. The grain yield was expressed on dry weight by adjusting 12.5% moisture content. Moreover, measurements such as plant height, ear length, ear width, number of cobs per plant and 1000 seeds weight were also done from net plot. Thousand seed weight was measured by counting 1000 seeds of maize from grain yield and then measuring its weight by sensitive balance.

Data Analysis: Analysis of variance for the response of treatments was done at the site level and then combined at the district level using R software (version 4.5.1, Foundation for statistical computing, 2011). Thus, about 810 experimental datasets were collected and analysed. Mean separation for the treatments was made for significant results as outlined by Cochran and Cox (1957) for situations with heterogeneous variance among treatments. Contrast analysis was done to compare positive control and other treatments. Graphs are generated using R software.

Results

Response of Maize Yield to Nutrient Types at Variable Sites: Tables 2 and 3 displayed that grain yield varied highly significantly ($p \leq 0.001$) from 79 % of trial sites, significantly ($p \leq 0.01$) from 17 % of trial sites, and non-significantly ($p > 0.05$) from 4% of trial sites. From 50 % of sites, lower yield ranging from 0.9 to 6.5 metric metric tons ha^{-1} yields were recorded without fertilizer application (negative control) whereas yield between 1.1 and 7.6 tha^{-1} was obtained from Nitrogen omitted treatment in the remaining experimental sites. The maximum grain yield (10.7 tha^{-1}) was recorded from All (NPKSZnB) applied treatments at trial site 9 in the study area. The higher grain yields (4.5-7.7 tha^{-1}) were attained from recommended NP treatment in 38 % of trial sites. From 5.1 to 8.8 tha^{-1} and 5.0 to 7.1 tha^{-1} of higher yields were recorded from the omission of Boron (All-B) and Zinc (All-Zn) treatments at four trial sites, respectively. About 43 percent of sites exhibited higher grain yields ranging from 3.5 to 10.1 tha^{-1} from the application of Sulphur with recommended Nitrogen and Phosphorus but not significantly differed from NP nutrients applied treatment. The remaining sites were shown higher yields (3.2-8.9 tha^{-1}) from the addition of recommended Nitrogen and Phosphorus fertilizers across all experimental sites.

Table2. Maize grain yield (tha^{-1}) response to nutrient types in Mecha [4], Ayehu Guagusa [4], and South Achefre [5] districts (2021/22)

Treatment	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13
All	8.9	5.8	6.7	6.8	6.2	4.4	4.3	7.7	10.7	5.9	7.8	6.3	6.2
All-B	8.8	6.7	6.8	7.1	6.8	3.5	3.1	7.1	9.2	6.0	7.0	6.9	7.6
All-Zn	8.1	5.5	6.9	6.9	5.5	3.8	4.2	7.9	8.9	5.4	7.0	6.1	7.1
All-S	8.5	6.5	6.9	6.7	6.4	4.0	4.7	5.0	9.7	6.2	7.8	6.1	7.6
All-K	8.1	6.6	6.8	6.8	6.0	4.9	4.1	5.6	8.0	7.2	7.2	5.2	6.6
All-P	5.2	4.2	4.5	3.0	5.6	4.4	3.8	7.1	9.6	3.2	6.1	3.0	3.9
RNP	8.3	6.9	6.9	6.4	5.8	4.0	4.3	6.4	8.9	7.3	7.0	6.2	7.7
NF	3.0	0.9	3.4	1.8	1.3	0.5	2.1	3.6	6.2	2.2	2.5	2.4	2.3
$NP+S_1$	8.6	5.8	6.8	7.4	5.1	3.4	4.6	7.9	10.1	6.9	7.0	6.7	5.9
All-N	3.4	1.1	2.7	1.6	1.3	0.8	2.0	5.1	7.6	2.1	2.7	1.9	1.7
LSD (0.05)	1.2	2.0	1.3	1.4	1.9	1.4	1.5	2.8	2.2	2.2	1.3	1.4	2.1
CV	9.8	23.6	13.1	15.0	22.3	24.1	23.5	25.6	14.7	24.7	12.4	16.1	19.4
SEM	0.42	0.43	0.30	0.42	0.41	0.39	0.28	0.22	0.30	0.41	0.36	0.36	0.43
p	***	***	***	***	***	***	**	*	*	***	***	***	***

Table3. Maize grain yield (tha^{-1}) response to nutrient types in Jabitehnan [3], Burie [2], and Womberma [5] districts (2021/22)

Treatment	Site 14	Site 15	Site 16	Site 17	Site 18	Site 19	Site 20	Site 21	Site 22	Site 23
All	6.7	3.8	4.6	4.3	4.4	3.8	5.7	6.7	4.8	2.3
All-B	7.2	2.9	4.4	4.6	4.7	4.0	4.4	6.3	5.1	3.6
All-Zn	6.7	3.2	4.4	5.0	5.2	4.3	3.6	6.3	4.2	2.9
All-S	7.4	3.2	4.7	4.6	4.8	4.3	5.1	6.8	4.9	2.6
All-K	7.1	3.2	4.8	4.6	4.7	5.0	5.8	6.1	4.7	3.5
All-P	6.9	2.9	3.5	3.1	3.1	4.3	3.8	5.5	4.3	2.9
RNP	7.5	3.2	4.0	4.7	4.9	5.6	4.4	6.0	4.8	4.5
NF	4.4	1.1	1.5	2.3	2.4	1.4	3.3	2.9	2.2	1.8
$NP+S_1$	7.3	3.5	4.4	4.0	4.1	3.6	5.1	6.1	5.0	3.8
All-N	3.6	1.9	1.1	2.7	2.8	2.4	4.0	3.7	1.7	1.7
LSD (0.05)	1.7	1.2	1.6	1.3	1.3	2.1	2.0	1.4	1.0	2.1
CV*	15.1	23.3	26.5	18.9	18.7	31.8	26.4	14.6	14.0	38.2
SEM	0.28	0.19	0.21	0.20	0.21	0.25	0.25	0.19	0.22	0.18
p	***	**	***	**	**	*	ns	***	***	ns

*CV: coefficient of variation, LSD: least significant difference, SEM: standard errors of the mean, ***: significant at 0.1 %. **: significant at 10 %., *: significant at 5 %, and ns: non-significance at 5 %.

Table 4 displays the combined results of nutrient effects on maize grain yield across sites. The combined analysis result in each district revealed that grain yield was highly significant ($p \leq 0.001$) in response to the application of nutrient types in all studied districts. The lowest grain yield from no fertilizer treatment (1.3 - 3.1tha^{-1}) was obtained from the Ayehu Guagusa midland, Mecha, Womberma, and Burie districts. Next to no fertilizer, All-N treatment also gained lower yields ranging from 1.8 to 5.2tha^{-1} in Jabitehnan and Ayehu Guagusa lowland districts. The highest (9 tha^{-1}) mean grain yield was recorded from the addition of NPKSZnB nutrients in the Ayehu Guagusa lowlands district compared to other studied districts. Fertilizer application of all nutrients provided 40-70% yield increment compared to no fertilizer application in the study districts.

Table4. The combined maize yield (tha^{-1}) response to nutrient types in the studied districts of North West Amhara (2021/22)

Treatment	Mecha	South Achefer	Ayehu Guagusa lowlands	Ayehu Guagusa midlands	Womberma	Burie	Jabitehnan
All	6.9 ± 0.38	6.6 ± 0.34	9.2 ± 0.70	4.3 ± 0.22	4.6 ± 0.49	4.4 ± 0.15	4.5 ± 0.50
All-B	7.0 ± 0.34	6.9 ± 0.36	8.2 ± 0.51	3.3 ± 0.36	4.7 ± 0.35	4.7 ± 0.14	4.3 ± 0.56
All-Zn	6.6 ± 0.31	6.4 ± 0.30	8.4 ± 0.26	4.0 ± 0.52	4.3 ± 0.38	5.1 ± 0.54	4.3 ± 0.54
All-S	7.0 ± 0.27	6.9 ± 0.40	7.4 ± 1.41	4.3 ± 0.39	4.7 ± 0.46	4.7 ± 0.20	4.4 ± 0.65
All-K	6.9 ± 0.23	6.6 ± 0.30	8.3 ± 0.30	4.5 ± 0.45	5.0 ± 0.34	4.6 ± 0.22	4.6 ± 0.54
All-P	4.5 ± 0.33	4.1 ± 0.41	8.3 ± 0.73	4.1 ± 0.18	4.2 ± 0.25	3.1 ± 0.31	3.9 ± 0.58
RNP	6.8 ± 0.33	7.1 ± 0.31	7.7 ± 0.70	4.2 ± 0.15	5.1 ± 0.32	4.8 ± 0.29	4.5 ± 0.58
NF	2.0 ± 0.29	2.4 ± 0.25	6.5 ± 1.34	1.3 ± 0.39	2.3 ± 0.22	2.4 ± 0.20	1.9 ± 0.48
RNP+S_1	6.7 ± 0.42	6.6 ± 0.27	9.0 ± 0.63	4.0 ± 0.44	4.7 ± 0.36	4.1 ± 0.34	4.5 ± 0.63
All-N	2.3 ± 0.46	2.1 ± 0.28	5.2 ± 1.16	1.4 ± 0.34	2.7 ± 0.29	2.8 ± 0.17	1.8 ± 0.38
CV*	18.2	18.1	15.7	24.0	24.2	17.0	25.2
p	***	***	***	***	***	***	***

**CV: Coefficient variation, Figures followed by ± sign are standard errors of the mean for each treatment, NF: no fertilizer. LSD: least significant difference.*

Role of Nutrients to Biological Grain Yield and Association with Yield Component Parameters: Figure 1 displays the mean percentage of deficient nutrients in the study area. About 55.3% of maize grain yield declined was recorded due to the absence of Nitrogen fertilizer application in the maize growing belts of the study area. Similarly, the omission of Phosphorus fertilizer reduced maize grain yield with a range of 24.5% over the study areas of north western Amhara of Ethiopia. With out fertilizer application 57.2% yield drop was observed.

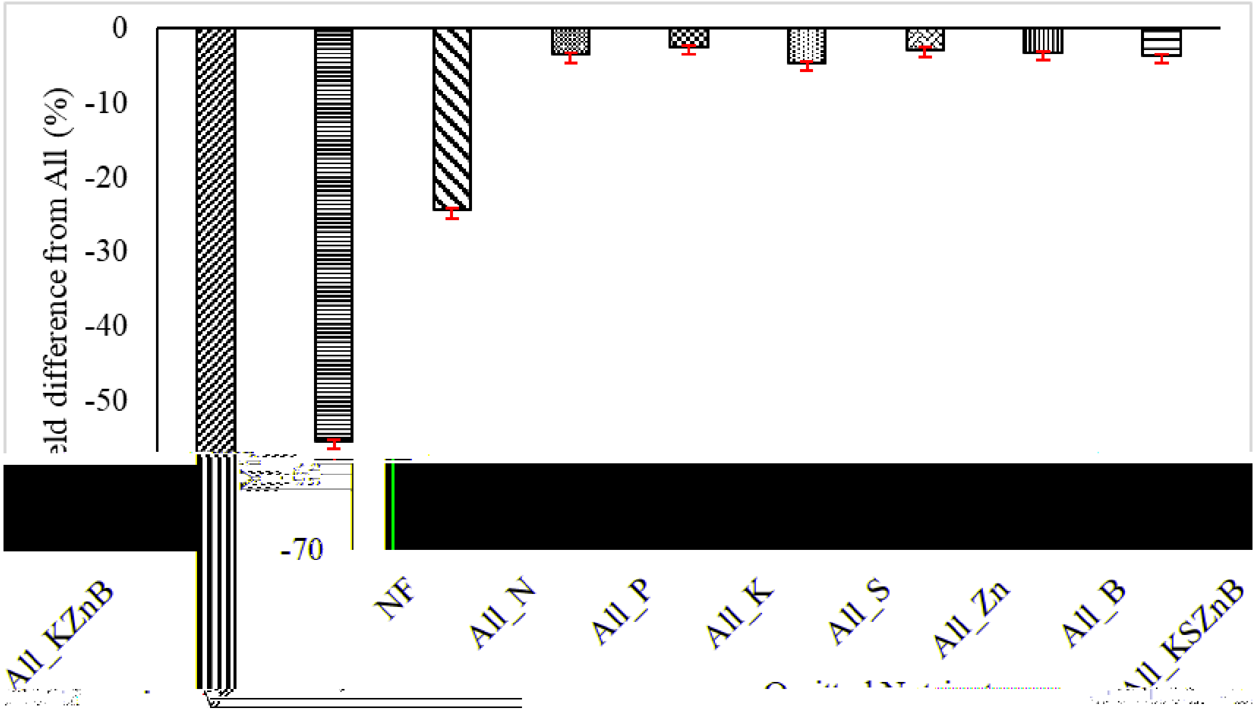

Figure 1. The contribution of each omitted nutrient in the study area

Correlation analysis showed 36 significant associations between all traits measured under the nutrient omission study (Table 5). Grain yield with crop parameters such as ear length (r =0.61***), ear diameter (r =0.61***), plant height (r = 0.46***), and thousand seed weight (r= 0.43***). All correlation analysis results showed highly significant ($p \leq 0.001$) positive associations between yield and yield component parameters. Highly significant ($p \leq 0.001$), but weak positive correlation (r=0.12) was also reordered between plant height and ear diameter whereas a strong positive correlation was recorded between grain yield and cob weight per plant (r = 0.89***). Figure 2 presents the application of all nutrients (NPKSZnB) and NP had a highly significant strong correlation (r = 0.7***) to maize yield.

Table5. Correlation matrix of yield and yield components of maize due to applications of different nutrient types across sites in North West Amhara (2021/22)

Parameters	Ph*	EL	ED	TSW	CwP	Gy	By	Sample size
Ph		***	**	***	***	***	***	810
EL	0.58		***	***	***	***	***	810
ED	0.12	0.53		***	***	***	***	750
TSW	0.43	0.31	0.29		***	***	***	238
CwP	0.43	0.59	0.62	0.48		***	***	779
Gy	0.46	0.61	0.61	0.43	0.89		***	810
By	0.68	0.62	0.36	0.52	0.64	0.63		810

**Ph: plant height, CwP: cob weight per plant, EL: ear length, ED: ear diameter, TSW: thousand seed weight, Gy: grain yield, and By: biomass yield*

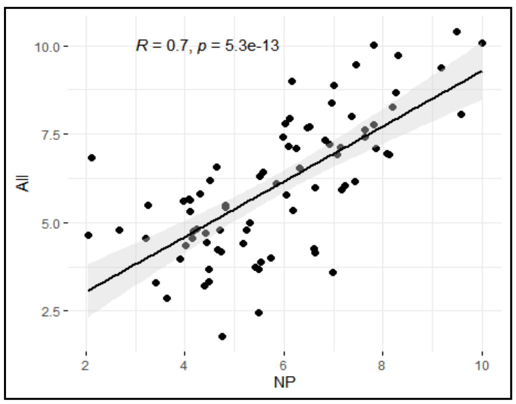

Figure 2. Maize grain yield (metric metric ton ha^{-1}) under All (NPKSZnB) and recommended NP nutrients across trial sites of study area (2021/22).

Discussion

Response of Grain Yield to Nutrients: The overall response of NPKSZnB application on maize yields varied across sites. The variation of nutrient responses from site to site indicates the need for site-specific nutrient management for crops. The variability in crop responses to nutrients supplied is a reflection of the intrinsic heterogeneity of soils among farmer fields, which is mostly brought on by soil management in the maize belt region of Ethiopia's Amhara Region (Balemi *et al*., 2019). Similar results were reported by Aliyu *et al*., (2021) maize yield is varied due to native soil variability in Nigeria, and sub-Saharan Africa (Kihara *et al*., 2016). The yield variability is happened due to spatial variability in the soil's nutrients supply capacity throughout the farmer's field. So, it is vital to assess of soil and environment for effective nutrient use to boost maize productivity.

The application of Nitrogen and Phosphorus was brought 100 yield increments compared to control treatment in Burie, Jabitehnan, South Achefer, Ayehu Guagusa midlands, and Mecha districts, whereas an increase of over 15 % was obtained in Ayehu Guagusa lowlands. This result shows that the addition of limiting nutrients as fertilizer is mandatory to improve crop production (van Beek *et al*., 2016; Mueller *et al*., 2012; Pradhan *et al*., 2015; Balemi, *et al*., 2019; Leitner *et al*., 2020; Yokamo *et al*., 2022). Nitrogen omission substantially reduced grain yield across all the studied districts owing to low Nitrogen soil content. There is severe Nitrogen nutrient depletion in Ethiopian highland soils (Haileslassie *et al*., 2005; van Beek *et al*., 2016; Mesfin *et al*., 2021). Our finding shows that Nitrogen is the most limiting nutrient to maize yield in the study areas. This tells the larger requirement of soils of the study area is Nitrogen fertilizer which signals high Nitrogen deficiency (Balemi *et al*., 2019; Amare *et al*., 2022; Hayashi, 2022).

The response to Phosphorus varied across sites with higher response observed from Mecha, South Achefer, and Burie districts due to a wide range of soil Phosphorus deficiency. Previous findings also indicated that the response of crop yield to N and P varied from site to site (Balemi, *et al*., 2019). Next to Nitrogen, the absence of Phosphorus is also limiting the maize yield in soils of maize growing belts (Girma, 2016; Pokharel *et al*., 2016). Preceding studies also indicate that Nitrogen and Phosphorus are widely deficient nutrient types in Ethiopian soils (EthioSIS, 2016). The present result agreed with many research findings that showed a reduced yield of maize in without Nitrogen and Phosphorus plots gave as compared to other plots in the study area as well as many parts of the country (Balemi *et al*., 2019; Amare *et al*., 2018; 2022). Thus, Nitrogen and Phosphorus are key nutrient types to boost crop productivity. However, grain yield was not declined due to Phosphorus omission in Ayehu Guagusa, and Womberma, districts which was in conformity with the finding of G. Selassie, (2016) who reported low P response in some soils of the Amhara region.

The analysis of variance shows non-significant grain yield differences among Potassium, Sulphur, Zinc, and Boron omitted treatments across all trial sites. The lack of response to Potassium and Sulphur nutrients suggests that KS nutrients are not a significant limiting nutrient in most of the soils in the study areas. This tells that the inherent Potassium and Sulphur-supplying capacity of the soils are relatively high in the Northwest Amhara region (G. Selassie *et al*., 2020; Amare *et al*., 2022). Yet, the need of supplying these nutrients is suggested by other findings in Ethiopia (Habtegebrial, and Singh, 2009; Bekele *et al*., 2022), and other countries (Rawal *et al*., 2018; Aliyu *et al*., 2021).

The omission of born and Zinc nutrients was shown inconsistently non-significant yield response in all studied districts. Either addition or omission of these nutrients leads increase grain yield of maize in some trial sites. This mighthave associated with soil variability across trial sites. Our finding indicates that the use of the micronutrients has not brought a substantial yield increase (Balemi *et al*., 2019; Amare *et al*., 2022). In contradiction with our result Alemu *et al*., (2016), Girma (2016) and EthioSIS (2016) reported that Zn and B nutrients are deficient in Ethiopian soils which must be added as mineral fertilizer.

The addition of Sulphur with recommended Nitrogen and Phosphorus gave almost equal non-significant grain yield compared with recommended Nitrogen and Phosphorus nutrients in all districts of Northwest Amhara, Ethiopia. Generally, recommended NP and NP plus Sulphur treatments show almost equal grain yield of maize in all study areas. So, the application of Sulphur might not be profitable in the farming system. Our result is contracted with the findings of EthioSIS, (2016) and Girma (2016) who reported that Sulphur is deficient in the soils of Ethiopia. The addition of all nutrients (NPKSZnB) and NP had similar trends across all trial sites. Both treatments have responded almost equally to maize yield. This tells us that only Nitrogen and Phosphorus have responsible to yield. Other added nutrients are not limiting due to their adequate delivery by the soils. Contrary to our findings Hailu *et al*., (2015) suggested application of NPKSZnB fertilizers in vertisols of central highlands of Ethiopia. Moreover, the addition of Sulphur and micronutrient fertilizers is suggested to enhance production in sub-Saharan Africa (Kihara *et al*., 2017).

Conclusions and Recommendations

The results of the soil analysis revealed that the soil of the study sites was deficient in Nitrogen and Phosphorus. The response of fertilizers to yield was significantly varied among soils from various sites. Nitrogen followed by Phosphorus nutrient omission declined maize yield in the study soils. Hence, Nitrogen and Phosphorus are the most yield-limiting nutrients in all trial sites. To reduce the production gap of maize in the farming system, these nutrients must be applied. The addition of Potassium, Sulphur, Zinc, and Boron nutrients did not significantly increase yield constantly compared to Nitrogen and Phosphorus nutrients in all experimental sites, and therefore, they are not yield limiting nutrients to improving yield targets. In conclusion, Nitrogen and Phosphorus nutrients are key fertilizer inputs to boost the yield of maize in Ethiopian highlands. This implies that the yield gap of maize should be minimized by addressing the demand for Nitrogen and Phosphorus fertilizers. Future assessment of Potassium, Sulphur, and micronutrients, which are not limiting for maize yield in this study, is recommended to decide their requirement in the farming system.

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