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Role of selected macro and micro nutrients on bread wheat (Triticum aestivum L.) productivity under Nitisols of North Western Amhara region, Ethiopia

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Abstract

Application of soil nutrients in the form of synthetic fertilizers is the primary option to enhance crop productivity and feeding over increased population size in Ethiopian context. An on-farm research was conducted in Amhara Region for the objective of identifying major yield-limiting nutrients on bread wheat (*Triticum aestivum L.)* productivity. The experiment was conducted in 2021 under rainy season on eighteen farm's fields which are located at three major wheat growing districts (Womberema-Burie, Yilmana Densa-Gonje and Deber Eliyas). It had a total of ten treatments (NPSZnBK, NPSZnK-B, NPSBK-Zn, NPZnBK-S, NPSZnB-K, NSZnBK-P, PSZnBK-N, NP, NPS2 and control). A randomized complete block design (RCBD) with three replications was used. Improved bread wheat variety TAY with 150 kg ha^{-1} seed rate and Urea, TSP (triple super phosphate), KCl (muriate of potash), $MgSO_4$ (magnesium sulphate), EDTA and Borax was used for the sources of N, P, K, S, Zn and B nutrients, respectively. Except urea, all fertilizer types were applied at planting using basal application. Urea fertilizer was applied at planting, tilering and butting stages of the crop using equal splits. Before planting, one composite soil sample from each experimental site was taken at 0-20 cm depth and analysed the selected soil parameters. Yield components such as plant height, spike length, and biological yields (grain & biomass) showed highly significant differences among treatment means at each individual experimental site as well as from combined analysis in the study districts. The main driving forces of those significant differences among treatment means in the ANOVA were due to omitting nitrogen and phosphorus nutrients. In the result, both yield components (plant height & spike length) and biological yields (grain & biomass) showed quick and automatic responses for nitrogen followed by phosphorus nutrient. Especially yield without nitrogen in all study districts is equivalent with yield attained from the control treatment even if all other nutrients are at optimal levels. However, both grain and biomass yields didn't show any significant differences either due to adding or omitting of sulphur (S), zinc (Zn), boron (B) and/or potassium (K) nutrients. This showed that, nitrogen (N) and phosphorus (P) nutrients are still the major bread wheat yield-limiting nutrients at Nitisols of North Western Amhara region, Ethiopia.

Keywords: bread wheat; nutrient; omission; yield; macro and micro

Introduction

Agriculture plays an important role in the Ethiopian economy. It contributes over 35% to the annual GDP, about 80% to the export earnings and it employs over 75% of the population (CSA, 2018). Of the agricultural GDP, the contribution from crop production takes the lion's share which is about 70% or more. Within the crop production system, the share of cereals in area coverage and production potential is about 80% and 85%, respectively (CSA, 2017). The most important three crops (wheat, maize and tef) have a share of 60% of the fertilizer inputs, 55% of the production area coverage and 60% of the annual production potential (CSA, 2017).

Wheat is the most widely cultivated cereal crop in the world, and provides 20% of the protein and calories consumed by the world population (FAOStat, 2013). It is currently the staple food for more than 35% of the global human population (FAOSTAT, 2013). Continues nutrient depletion, newly emerging diseases and pests and unstable weather conditions deriving from climate change are the major threats for declining wheat productivity globally (CIMMYT, 2016). Ethiopia is the second-largest wheat producer in Sub-Saharan Africa, following South Africa (White *et al.*, 2001). The crop covers 1.7 million ha area and 4.6 million tons production (CSA, 2018). From the country, Amhara Region accounts 32.7% of area coverage and 30.3% of production volume (CSA, 2018). However, average wheat productivity in the Amhara region is about 2.53 tons ha^{-1} which is below the national average 2.74 tons ha^{-1}.

After the introduction of soil fertility map by the Ethiopian Soil Information System (EthioSIS, 2015) and the second growth and transformation plan (GTP II, 2016-2020), the country has increased the fertilizer types used from two to six. For this reason, the annual import and consumption raised to over 100,000 tonns $year^{-1}$. Currently, Ethiopia imports about 1.4 million tonns of multi nutrient fertilizers and projected to use over 2 million tons at the end of 2025. In targeting the right fertilizers to the right places, the EthioSIS project team has mapped the soil nutrient status of agricultural lands in Ethiopia and identified that a number of essential nutrients are deficient and critically required for enhancing crop productivity in the country. Based on the developed map by the project, N, P, K, S, B, Zn, Fe and Cu are the deficient nutrients identified and recommended for enhancing crop productivity in most of Ethiopian soils. Even though the newly formulated fertilizers needed a validation work, Agricultural Transformation Agency (ATA) and Ministry of agriculture (MoA) in collaboration conducted direct demonstration trials over at 60,000 trial sites within the regions. Due to this, the country has already customized the use of above-mentioned soil nutrients and made available in fertilizer forms without reaching national consciences on the importance of those newly formulated fertilizer types. Therefore, this activity was conducted for the objective of identifying major yield-limiting nutrients for bread wheat productivity in North Western Amhara region, Ethiopia.

Materials and methods

Study area description

The experiment was conducted at three major bread wheat growing districts (Womberema-Burie, Yilmana Densa-Gonje and Deber Eliyas) in Amhara regional state and located in North West direction from the capital city of Ethiopia (Fig 1).

Experimental materials

Improved bread wheat variety (TAY) with 150 kg ha^{-1} seed rate was used. Urea, TSP, KCl, MgSO4, EDTA and Borax was used as a source of N, P, K, S, Zn and B nutrients, respectively. Soil auger and core-sampler was used to collect soil samples.

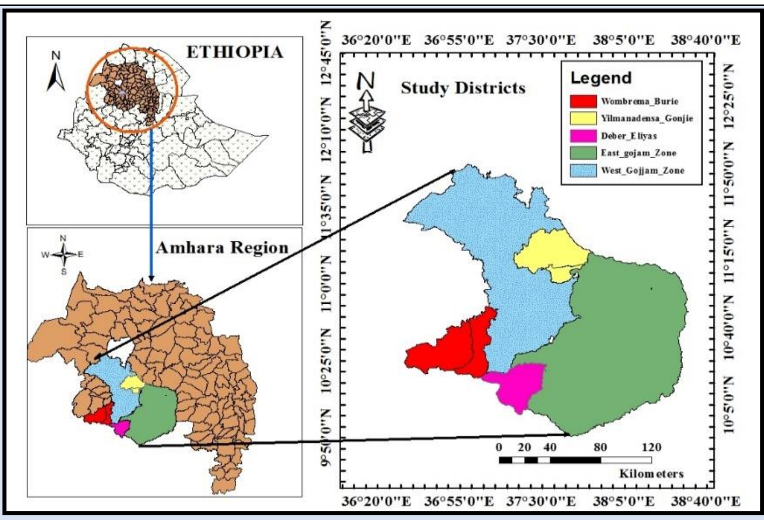

Figure 1: Map of the study districts

Experimental methods and design

The experiment was conducted in 2021 at eighteen (18) farmer's fields. A randomized complete block design (RCBD) with three replications was used. The test crop was planted in row planting method using 20 cm row spacing. Spacing between plots and blocks were also 1m and 1.5m, respectively. From $12m^2$ gross plot size, $9.6m^2$ was used as net harvestable area. The experiment had a total of ten treatments as indicated in Table 1. Except Urea, all fertilizers were applied at planting time using band application method. Urea fertilizer was applied in three equal splits at different crop stages (planting, tilering and butting).

Table 1: Treatment setup used in the experiment

No	Treatment	Description	Nutrient application rates (kg ha^{-1})					
			N	P_2O_5	K_2O	S	Zn	B
1	NPSZnBK	All	138	92	60	10.5	5	1
2	NPSZnK-B	B-omitted	138	92	60	10.5	5	-
3	NPSBK-Zn	Zn-omitted	138	92	60	10.5	-	1
4	NPBZnK -S	S-omitted	138	92	60	-	5	1
5	NPSZnB-K	K-omitted	138	92	-	10.5	5	1
6	NSZnBK-P	P-omitted	138	-	60	10.5	5	1
7	NP	NP alone	138	92	-	-	-	-
8	Control	No fertilizer	-	-	-	-	-	-
9	NP+S2	NPS alone	138	92	-	30	-	-
10	PSZnBK -N	N-omitted	-	92	60	10.5	5	1

Soil sampling, Preparation and Analysis

From each experimental site, one composite soil sample before planting was taken from five points following X-pattern sampling technique at the depth of 0-20 cm. The sample was air dried and sieved using ≤2 mm sieve for the analysis of the required parameters. Soil pH, organic carbon (SOC), cation exchange capacity (CEC), available phosphorus (AP) and total nitrogen (TN) were analyzed. All the mentioned parameters were analysed at Adet agricultural research centre's (AARC) soil laboratory. Besides, soil pH was determined using 1:2.5 soil-water suspensions ratios according to Taye *et al.*, 2002. Olsen (1954) was used for AP analysis. TN was analysed following Kjeldahl method (Bremner and Mulvaney, 1982). Soil OC was determined using wet oxidation and CEC determined using ammonium acetate method. As indicated in Table 2, Soil pH values of the experimental sites found from strongly (4.5-5.2) to moderately acidic (5.3-5.9) ranges based on (Tekalign, 1991). Average soil AP values ranged in medium (5-10) based on Olsen (1954) nutrient rating scale. Based on Tekalign (1991) soil OC and TN values found from low to medium nutrient levels. While, CEC reading from medium (15-25) to high (25-40) Cmol$_{(+)}$kg^{-1} rating level according to Hazelton and Murphy (2007).

Table 2: Before planting selected soil properties for experimental sites

Parameters		Wombrema-Burie	Yilmana Densa-Gonje	Deber Eliyas	Rating level	Reference
pH	min	4.97	5.30	4.85	Strongly-moderately acidic	Tekalign (1991)
	max	5.13	5.75	5.27		
	Mean	5.46	5.48	5.06		
Ap ppm	min	7.08	4.42	3.09	Medium	Olsen et al. (1954)
	max	10.56	8.34	7.79		
	Mean	8.89	6.17	5.61		
SOC %	min	1.482	0.437	0.971	Low-medium	Tekalign (1991)
	max	2.746	1.673	2.129		
	Mean	2.102	1.142	1.716		
TN [%]	min	0.153	0.055	0.095	Low-medium	Tekalign (1991)
	max	0.155	0.164	0.238		
	Mean	0.154	0.101	0.180		
CEC	min	26.40	23.92	20.22	Medium-High	
	max	27.70	30.36	33.92		Murphy (2007)
	Mean	27.05	26.65	27.67		

Data collection and analysis

Important agronomic data like plant height, spike length and biological yields (grain and biomass) were collected and analysed. Direct weighted grain yield was adjusted to 12.5% of moisture content. Before running any statistical analysis, normality and homogeneity of the collected data were tested using Shapiro & Levene tests by R software version 4.2.2.

Then, the effect of independent variables on dependent variables was statistically tested. Analysis of variance (ANOVA) was carried out to assess the difference among treatments using Statistical Analysis System (SAS, 2002). Least significant difference (LSD) was used for mean separation @ 5% probability. ANOVA was also done to yield penalties on the test crop among treatments.

Results and Discussion

Plant height and spike length

Plant height of bread wheat showed highly significant difference among treatment means at the study districts (Table 3). The significant differences generated from the comparison of N omitted, P omitted and control treatment with other remaining treatments. Except nitrogen and phosphorus, plant height of the test crop didn't show significant responses for other nutrients either the nutrients added or omitted. As shown in the ANOVA Table, the minimum plant height values recorded at control, N-omitted and P-omitted treatments in ascending order. But the maximum values observed at any one of the treatments which received nitrogen and phosphorus nutrients together. This shows that, how much nitrogen and phosphorus nutrients potentially determining performances of yield components of bread wheat in the study districts. All the trends showed on plant height also repeated on spike length of bread wheat at all study districts.

Table 3: Combined plant height and spike length of bread wheat in the study districts

Treatment	Wombrema-Burie (cm)		Debre Eliyas (cm)		Yilmana Densa-Gonjie (cm)	
	PH	SL	PH	SL	PH	SL
NPSZnBK	96.4	9.1	86.4	7.6	93.7	9.1
NPZnBK-B	96.9	9.2	88.3	7.8	91.7	9.1
NPSBK-Zn	98.3	9.0	88.5	8.1	93.9	9.0
NPSZnK-S	96.3	9.0	85.0	7.5	93.2	9.1
NPSZnB-K	97.7	9.3	84.8	7.8	90.7	8.9
NSZnBK-P	95.9	9.2	81.7	7.5	89.6	9.0
NP	97.7	9.1	86.5	7.8	90.0	8.8
Control	82.7	8.3	58.9	5.7	58.5	6.3
NP+S2	97.0	9.2	86.2	7.9	91.3	9.2
PSZnBK-N	86.2	8.3	62.9	6.0	65.7	6.9
LSD (0.05)	4.6**	0.3**	4.9**	0.6**	3.9**	0.6**
CV	9.0	6.0	8.3	12.2	5.7	9.0

*Note: PH= Plant height, SL=Spike length, ** = highly significant, * = Significant, NS = non-significant*

Grain and Biomass yields

In Wombrema-Burie district, grain yield of bread wheat showed highly significant difference among treatment means except at one site (Table 4). Most of the observed significant differences among treatment means of the grain yield in the district derived due to control and N omission treatments, respectively. In the other saying, significant difference generated due to the presence of control and N omitted treatments. Almost at all trial sites, the minimum grain yield values recorded at control treatments followed by N omitted treatment. However, the maximum values were observed at any one of the treatments which received N and P nutrients together.

In the study district, an automatic response on grain yields of bread wheat was observed when either N nutrient was added or omitted. In this district, omitting of phosphorus nutrient also didn't show significant difference from treatments which received recommended N and P nutrients together. This might indicate us to revise the current P rate to be used in the coming years. This showed that, N still showed its primarily potential on wheat yield-limiting which is in line with the findings of (Tadele *et al.*, 2018) as he stated, the yield-limiting nutrients to produce maize and wheat in major growing areas in Amhara region were N and P, respectively. Exception of N omitted treatment, significant differences didn't occur among the means of other treatments due to either adding or omitting of other nutrients (S, Zn, B, K and P) in the district.

Table 4: Grain yield values of bread wheat at Wombrema-Burie district

Treatment	Grain yield (kg ha^{-1})								
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
NPSZnBK	5192	4970	4263	4302	2814	3598	3313	3437	3548
NPZnBK-B	5153	5118	4365	4325	2775	2965	3171	3202	3632
NPSBK-Zn	4890	5026	4320	5020	2858	3360	3268	3341	4278
NPSZnK-S	5110	5106	4520	3963	2769	3172	3284	3273	3888
NPSZnB-K	4277	4887	4220	3811	2987	2965	2871	3297	4382
NSZnBK-P	4802	4854	4574	3836	2864	3102	3269	3539	3629
NP	4807	5015	4007	3975	2885	3050	2994	3435	3984
Control	3782	4219	1740	1867	339	1036	1308	1231	1201
NP+S2	4782	4660	4183	4049	2792	2590	2975	3454	3665
PSZnBK-N	2940	4351	1858	2138	865	1510	1735	1279	2057
LSD (0.05)	511**	1019NS	569**	1091**	794**	611**	734**	738**	997**
CV	6.6	12.4	8.8	17.2	19.5	13.1	15.3	14.7	17.1

*Note: ** = Highly significant, * = Significant, NS = non-significant*

Similar to Wombrema-Burie, in the two districts (Yilmana Densa-Gonjie and Deber Eliyas), grain yield of bread wheat also showed highly significant difference among treatment means (Table 5). But unlike Wombrema-Burie, P omission also sourced for the significant differences among treatment means of bread wheat grain yield in addition to control and N omitting treatments (Table 4). This showed that, P is the second yield-limiting nutrient in these study districts which is in line with the findings of (Tadele *et al.*, 2018). Overall trends of the experiment showed, N and P nutrients are still the major yield-limiting nutrients for bread wheat productivity in Nitisols of North Western Amhara region.

Table 5: Grain yield values of bread wheat at Yilmana Densa-Gonjie and Deber Eliyas districts

Treatment	Yilmana Densa-Gonjie (kg ha^{-1})				Deber Eliyas (kg ha^{-1})				
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 5
NPSZnBK	3275	3590	4252	4164	2835	2813	1752	2453	3686
NPZnBK-B	3100	3869	4116	4305	2787	2721	1742	2525	3179
NPSBK-Zn	3331	4061	4131	4177	2296	2863	1928	2219	3523
NPSZnK-S	3146	3861	3846	4387	2707	2932	1869	2343	2971
NPSZnB-K	2831	4026	4079	3946	1912	2612	1918	1891	3727
NSZnBK-P	2696	3096	2724	4004	1564	1675	2435	2010	2776
NP	3018	3401	3149	3481	1824	2669	2534	1850	3419
Control	255	300	854	1158	450	410	641	243	1295
NP+S2	2750	3476	3798	3982	2292	3005	2077	2333	3878
PSZnBK-N	695	937	1255	1401	454	655	791	359	1678
LSD (0.05)	572**	845**	597**	358**	486**	505**	1069**	760**	991**
CV	13.4	16.2	10.9	6.0	14.9	13.3	35.5	24.5	19.3

*Note: ** = Highly significant, * = Significant, NS = non-significant*

Except at one site in Wombrema-Burie study area, biomass yield of bread wheat showed significant difference among treatment means (Table 6). Similar to grain yield results, significant difference among treatment means for biomass yield was also generated from N omitting and control treatments in comparison with other remaining treatments. Except at two sites, the minimum biomass yield values recorded at control treatment followed by N omitted treatment in the study districts. However, the maximum values recorded at any one of the treatments which received N and P nutrients together. Automatic biomass yield reduction was observed when either of the two or both of major nutrients (N and P) was omitted. Phosphorus omitted treatment in this district didn't show any statistically significant difference from treatments having N and P nutrients together at a time. Inversely, N showed its major impact on determination of bread wheat biomass yield in the district. Similar to grain yield, no significant differences were observed on biomass yields either due to adding or omitting of S, Zn, B and K nutrients.

Similar to Wombrema-Burie, at Yilmana Densa-Gonjie and Deber Eliyas districts, biomass yield of bread wheat also showed highly significant difference among treatment means. But unlike Wombrema-Burie district, omitting P nutrient also caused for the significant differences among treatment means of bread wheat biomass yield in addition to control and N omitted treatments (Table 7). This showed that, P is the second wheat yield-limiting nutrient in the study districts which is in line with the finding of (Tadele *et al.*, 2018).

Table 6: Biomass yield values of bread wheat at Wombrema-Burie district

Treatment	Biomass yield (kg ha^{-1})								
	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
NPSZnBK	11080	9635	9382	9924	7444	7927	6597	9010	9615
NPZnBK-B	10938	10632	9365	10458	7809	7639	7420	9090	9299
NPSBK-Zn	10069	10747	9785	8958	7483	7799	7653	9757	10337
NPSZnK-S	10736	10563	10007	9326	7510	8038	6295	9715	9778
NPSZnB-K	9444	10715	9458	9573	7618	7448	5795	9036	10736
NSZnBK-P	10003	8924	9497	9201	7479	6573	6347	9569	8788
NP	10432	10493	9552	8557	6017	7337	6153	8556	9830
Control	7799	8569	3882	4260	1257	2208	2587	5566	3469
NP+S2	10521	8795	9399	10212	7733	6236	7170	9882	8569
PSZnBK-N	7448	9243	6250	4743	2569	2361	3809	5476	5073
LSD (0.05)	1715**	3296^{NS}	1913**	1547**	2073**	1203**	2350**	2629*	1984**
CV	10.2	19.7	13.0	10.7	19.3	11.1	23.1	18.0	13.6

*Note: ** = Highly significant, * = Significant, NS = non-significant*

Table 7: Biomass yield values at Yilmana Densa-Gonjie and Deber Eliyas districts

Treatment	Yilmana Densa-Gonje (kg ha^{-1})				Deber Eliyas (kg ha^{-1})				
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4	Site 5
NPSZnBK	8855	9427	9415	9827	8708	5990	4260	6840	7833
NPZnBK-B	8264	9960	9837	10130	8160	5382	5101	6774	6740
NPSBK-Zn	8642	10236	9634	10105	7194	7052	5135	6278	8351
NPSZnK-S	8393	9830	9151	10518	8151	7729	4781	6438	6323
NPSZnB-K	7718	10766	9365	9550	7080	6521	5526	5757	7932
NSZnBK-P	6926	8700	6620	9754	5351	4337	6870	5358	5792
NP	7000	9495	7484	9382	4672	6703	7052	5938	7594
Control	981	1167	2267	2995	2201	1288	1944	858	2910
NP+S2	7806	9332	8696	9660	7314	7583	5285	6670	8597
PSZnBK-N	2043	2588	3299	3197	1896	1646	1538	1153	3354
LSD (0.05)	1405**	2000**	1267**	700**	1120**	1775**	2893**	1448**	1845**
CV	12.4	14.4	9.8	4.8	10.8	19.2	35.8	16.3	16.6

*Note: ** = Highly significant, * = Significant, NS = non-significant*

Similar to the individual experimental sites, all the biological yields (grain and biomass) showed significant difference among treatment means (Table 8). As discussed for the individual sites, in the combined ANOVA result, P omitting didn't show significant difference from treatments which received recommended N and P nutrients together at a time.

Table 8: Combined grain and biomass yield of bread wheat (kg ha^{-1}) in the study districts

Treatment	Wombrema-Burie (kg ha^{-1})		Debre Eliyas (kg ha^{-1})		Yilmana Densa-Gonjie (kg ha^{-1})	
	Grain yield	Biomass yield	Grain yield	Biomass yield	Grain yield	Biomass yield
NPSZnBK	3938	8957	2708	6726	3820	9381
NPZnBK-B	3856	9183	2591	6431	3848	9548
NPSBK-Zn	3862	9176	2566	6802	3917	9647
NPSZnK-S	3898	9108	2564	6684	3810	9473
NPSZnB-K	3744	8869	2412	6563	3720	9349
NSZnBK-P	3830	8487	2092	5541	3130	8000
NP	3740	8496	2459	6392	3262	8340
Control	1858	4400	608	1840	642	1853
NP+S2	3683	8724	2717	7090	3502	8873
PSZnBK-N	2081	5219	788	1917	1072	2782
LSD (0.05)	526**	1031**	497**	1037**	430**	919**
CV	28.5	23.9	32.0	25.7	17.3	14.7

*Note: * * = Highly significant, * = Significant, NS = non-significant*

Except control and N omitted treatments other treatments didn't show any statistically significant differences with each other on both grain and biomass yields. In this finding, N showed as a leading yield-limiting nutrient for bread wheat productivity in the Nitisols of North Western Amhara region followed by P which is agreed with (Tadele *et al.*, 2022) finding. In most of the study districts, omitting of each nutrient contributed yield penalty in comparison to the bench mark treatment (NPSZnBK). However, the contribution of each nutrient on the yield penalties didn't show equal magnitude. Even, omitting of some nutrients showed yield advantages from the bench mark treatment. With these remarks, omitting of K, S, B and Zn nutrients contribute insignificant impact from the bench mark treatment which is agreed with the findings reported by Ayana *et al.* (2022) and Beamlaku *et al.* (2022). However, impact of omitting N and P nutrients showed high and significant from the treatment which received all type of nutrients, respectively. Especially, yield penalties due to omitting nutrient N is nearly equivalent to the control (zero input) treatment (Figure 2).

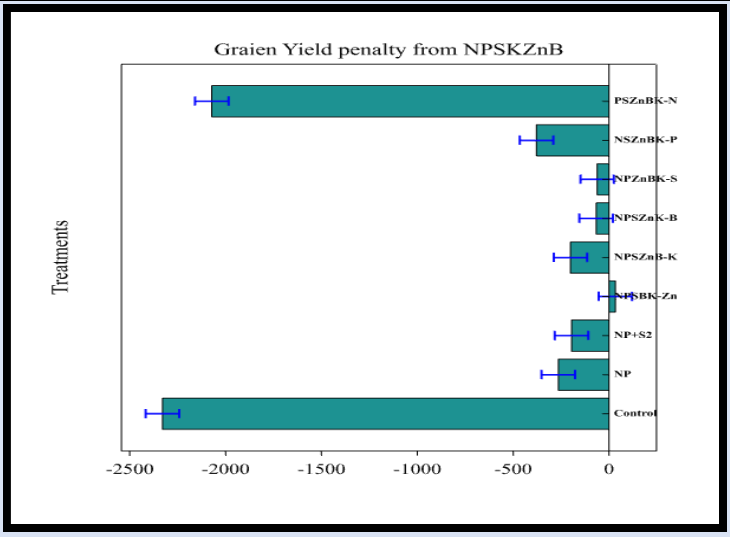

Figure 2: Yield penalty /advantage of bread wheat grain yield due to omitting of nutrients (##: NPSZnBK is a benchmark treatment for this analysis)

Figure 3: Trial performance sample at each study district (2021)

Conclusion

Grain yield of bread wheat showed highly significant differences among treatment means at each individual experimental site as well as at all study district. The study confirmed that, N is the primary bread wheat yield-limiting nutrient in North Western Amhara region Nitisols followed by P. However, S, Zn, B and K nutrients had no significant responses from the bench mark treatment (NPSZnBK) or the former nutrients used (sole NP) on both grain and biomass yields of bread wheat either due to added or omitted them. Therefore, still it is possible to maximize bread wheat yield productivity by using optimal N and P nutrient levels with integrating other improved technologies in the study districts and areas having similar soil type & agro-ecology. However, frequent revision of the soil fertility status is too important for updating nutrient requirements both in types and rates used for enhancing productivity and production of bread wheat in North Western Amhara region, Ethiopia.

Declarations

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Statements and Declarations

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Conflict of interest

We declared that there is no conflict of interest to the best of our knowledge.

Author Contributions

Erkihun Alemu, Tadele Amare, Zerfu Bazie, Tesfaye Feyisa, and Ateneh Abewa were participated on designing, implementing, analyzing the data and writing the manuscript. While, Abere Tenagne, Abreham Awoke, Atakltie Abebe, Zelalem Addis, Bitewlign Kerebeh, Zemie Amibawu, Sefinew Wale and Beamlaku Alemayehu were participated on data collection, executing the field work, and input preparation during experimentation.

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