11. Identifying Major Yield-Limiting Nutrients for Bread Wheat (*Triticum Aestivum* L.) in Major Wheat Growing Areas of North Western Amhara, 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. On-farm research was conducted in Amhara Region with the objective of identifying major yield-limiting nutrients on bread wheat (Triticum aestivum L.) productivity. The experiment was conducted in 2021 under rain-feed cropping season on eighteen farms fields which are located at three major wheat growing domains (Womberema-Burie, Yilmana Densa-Gonje and Deber Eliyas). Ithad a total of ten treatments [NPSZnBK, NPSZnK-B, NPSBK-Zn, NPZnBK-S, NPSZnB-K, NSZnBK-P, PSZnBK-N, NP, NPS2 and control (no input)].

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 tha^{-1} which is below the national average 2.74 tha^{-1}.

Due to increased use of agricultural inputs (improved seeds, fertilizers and pesticides), agriculture showed a dramatic progress with the annual growth rate of over 8%. Particular

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 fertilizer types 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 and they confirmed what the EthioSIS soil map saying. However, this work had a major limitation from different aspects. Now, the problem is that the country has already customized the use of above-mentioned soil nutrients and made available in fertilizer form and appeared on the fertilizer market before the validation studies were reported. Although the new formulated fertilizers available on the fertilizer market, there is no national/regional conscience on the importance of those newly formulated fertilizer types. Therefore, this activity was conducted with the objective of identifying major yield-limiting nutrients for bread wheat productivity in North West Amhara Region, Ethiopia.

Materials and Methods

Study Area Description: The experiment was conducted at three major 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 Kgha^{-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.

Experimental Methods and Design: The experiment was conducted in 2021 at 18 farmers' field. Randomized complete block design (RCBD) with three replications were used. Row planting method was used. Spacing between rows, plots and blocks was 0.2m, 1m and 1.5m, respectively. Gross plot size used was 4m x 3m and harvested 9.6 m^2 areas. The experimenthad a total of ten treatments as indicated in Table 1. Except Urea, all fertilizers were applied at planting using basal application. Urea fertilizer was applied in three equal splits at different crop stages (planting, tilering and butting).

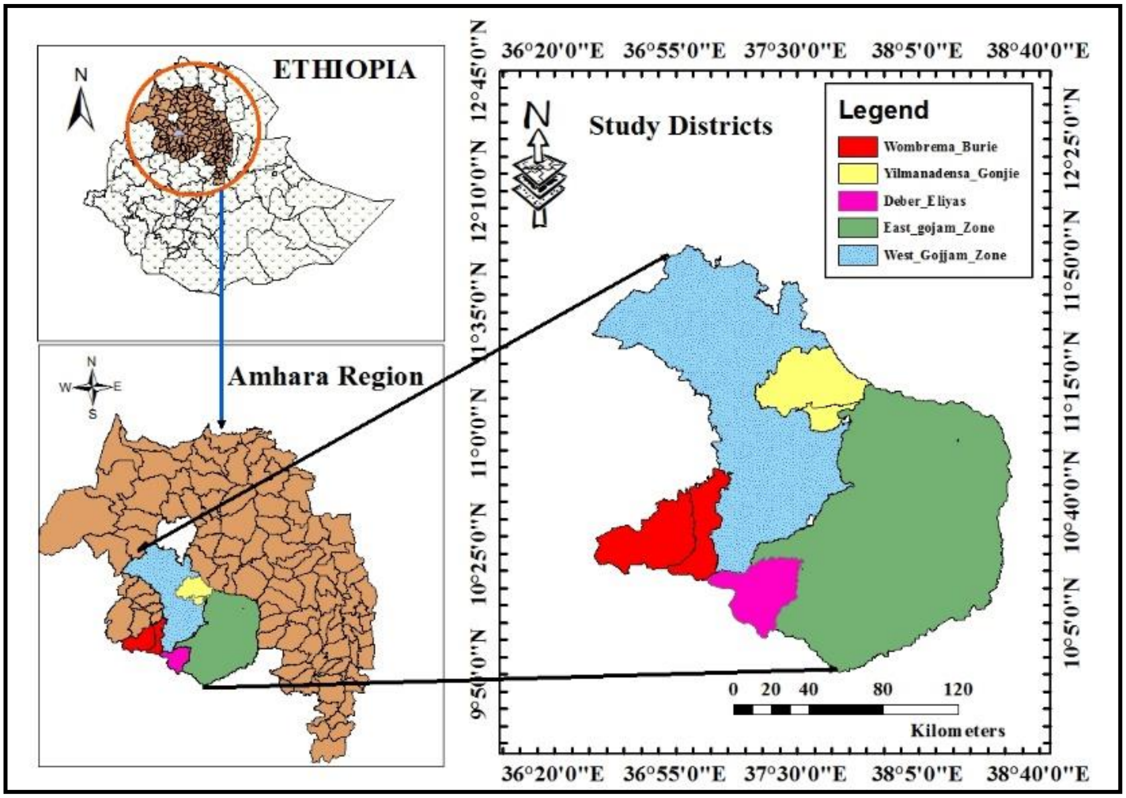

Figure 12.Map of the study districts

Table 1. Treatment setup for the on-farm experiment

No	Treatment	Description	Nutrient application rates ($Kgha^{-1}$)					
			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	-

In the study district, an automatic response on grain yields of bread wheat was observed when either N nutrient was added or omitted. Even in this district, Phosphorus omission didn't show a 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*. With the exception of N nutrient, significant difference didn't occur among the means of bread wheat grain yield either due to addition or omission of other nutrients (S, Zn, B, K and P) in the study district.

Table 3. Grain yield of bread wheat values at Wombrema-Burie

Treatment	Grain yield (Kgha^{-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**	1019^{NS}	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, Yilmana Densa-Gonjie and Deber Eliyas domains, grain yield of bread wheat also showed a highly significant difference among treatment means (Table 4). But unlike Wombrema-Burie, P omission also caused 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). As an overall trend in the conducted experiment, N and P nutrients are still the major wheat yield-limiting nutrients in most of North West Amhara.

Table4. Grain yield values of wheat at Yilmana Densa-Gonjie and Deber Eliyas districts

Treatment	Yilmana Densa-Gonjie ($Kgha^{-1}$)				Deber Eliyas ($Kgha^{-1}$)				
	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 5). 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. As an exception to the two sites, the minimum biomass yield values recorded at control treatment followed by N omitting treatment in the study domain. However, the maximum values recorded at any one of the treatments which received N and P nutrients together. An automatic biomass yield reduction was observed when either of the two or both of major nutrients (N and P) was omitted. Phosphorus omitting treatment in this domain didn't show a significant difference from a treatment which received recommended N and P nutrients together. Inversely in the study districts, N showed its major impact on determination of bread wheat biomass yield. Similar to grain yield, no significant differences were observed on biomass yields of bread wheat either due to adding or omitting of S, Zn, B and K nutrients.

Table5. Biomass yield of bread wheat values at Wombrema-Burie

Treatment	Biomass yield (Kgha^{-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**	3296NS	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

Similar to Wombrema-Burie, Yilmana Densa-Gonjie and Deber Eliyas districts, biomass yield of bread wheat also showed a highly significant difference among treatment means. But unlike Wombrema domain, P omitting also caused for the significant differences among treatment means of bread wheat biomass yield in addition to control and N omitting treatments (Table 6). This showed that, P is the second wheat yield-limiting nutrient in the study domains which is in line with the finding of (Tadele *et al.*, 2018).

Similar to the individual experimental sites, all the biological yields (grain and biomass) showed significant difference among treatment means (Table 7). As discussed for the individual sites, in the combined ANOVA, P omitting didn't show a significant difference from treatments which received recommended N and P nutrients together. Except control and N omitted treatments other treatments didn't show any significant difference with each other on both grain and biomass yields. Therefore, N is still the leading yield limiting nutrient in Ethiopian soils followed by P which is in line with (Tadele *et al.*, 2022) finding, as he explained, *the yield-limiting nutrients to produce wheat in major wheat-growing areas in Amhara region were N and P, respectively*.

Table6. Biomass yield values at Yilmana Densa-Gonjie and Deber Eliyas

Treatment	Yilmana Densa-Gonje (Kgha^{-1})				Deber Eliyas (Kgha^{-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

Table7. Combined grain and biomass yields of bread wheat at each study domain (Kgha^{-1})

Treatment	Wombrema-Burie (Kgha^{-1})		Debre Eliyas (Kgha^{-1})		Yilmana Densa-Gonjie (Kgha^{-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

In most of the study districts, omitting of each nutrient contributed yield penalty in comparison to the bench mark treatment (treatment which received all type of nutrients). However, the contribution of each nutrient on the yield penalties didn't show equal magnitude. Even, omitting of some nutrients provided a yield advantage from the bench mark treatment (NPSZnBK). With these remarks, omitting of K, S, B and Zn nutrients contribute insignificant impact from the bench mark treatment. However, impact of omitting N and P nutrients showed high and significant from the treatment which received all type of nutrients, respectively (Figure 2). Especially impact of N omitting is nearly equivalent to zero input treatment.

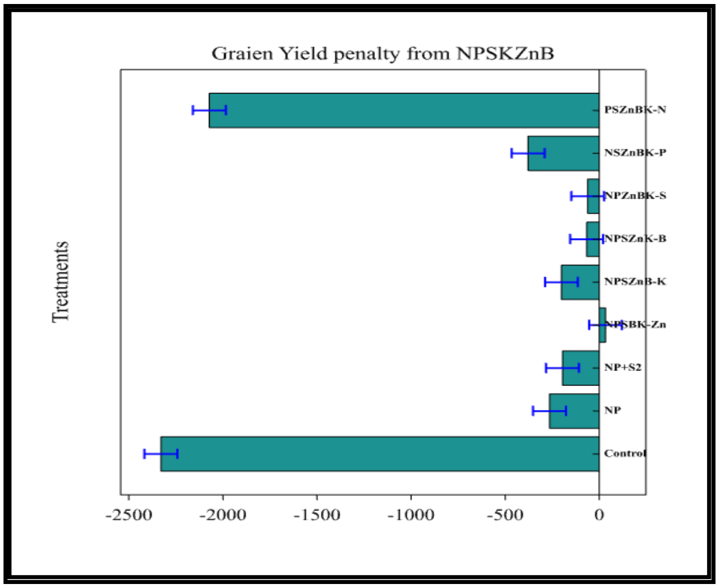

Figure 13.Yield penalty /advantage of bread wheat grain yield due to omitting of nutrients

(*: NPSZnBK is a benchmark treatment for this analysis)

In all study districts, grain yield of wheat showed highly and positive significant correlation with yield components like plant height, spike length and biomass yield. Similarly, yield components by themselves also showed highly and positive significant correlation with each other (Table 8).

Table8. Correlation of bread wheat yield components with grain yield at the three districts

Parameter	Yilmana Densa-Gonjie			Wombrema-Burie		
	PH*	SL	GY	PH	SL	GY
PH	-			-		
SL	0.83	-		0.63	-	
GY	0.93	0.74	-	0.54	0.57	-
BMY	0.96	0.76	0.98	0.55	0.51	0.84
Parameter	Debre Eliyas					
	PH	SL	GY	**PH=plant height, SL=spike length, GY=grain yield, BMY=biomass yield, **=Correlation is significant at p<0.01; *=Correlation is significant at p<0.05 & ns=Correlation is non-significant*		
PH	-					
SL	0.69	-				
GY	0.78	0.58	-			
BMY	0.77	0.71	0.90			

Conclusion

Grain yield of wheat showed a highly significant difference among treatment means at each individual site as well as at all study domains. The study confirmed that, N is the primary wheat yield-limiting nutrient followed by P which is in line with the previous results reported by AARC. However, S, Zn, B and K nutrients had no significant statistical response from the former nutrients used (N and P) on both grain and biomass yields of wheat either when we add or omit them. Therefore, still it is possible to maximize wheat yield by using N and P fertilizer sources with the integration of other improved technologies. However, frequent revision of the soil fertility status is too important for updating nutrient requirements both in types and amounts used for enhancing wheat productivity and production in the study districts.

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