2. Yield-Limiting Nutrients for Tef on Vertisols of the Central Highlands of Ethiopia

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Abstract

Tef production and productivity in Ethiopia are influenced by different factors. Understanding and prioritizing the most important factors is the first step in increasing tef production. One of the most important factors affecting tef yield is the application of suboptimal and unbalanced nutrients to the crop. The experiment was conducted in 2021 in Siyadebrna Wayu on 8

most important yield limiting nutrients for tef and to investigate the indigenous soil supply of macro- and micronutrients for tef production. The experiment consists of ten treatments including: NPKSZnB (All), NPKSZn (All-B), NPKSB (All-Zn), NPKZnB (All-S), NPSZnB (All-K), NKSZnB (All-P), PKSZnB (All-N), NP (Recommended NP), NP+S2 and control (without nutrient). The treatments were laid out in a randomized complete block design with three replications. Composite soil samples were collected from each site before planting from a depth of 0 20 cm for the analysis of selected soil properties. The analysis of variance showed that plant height, panicle length, biomass yield, grain yield, and harvest index, were significantly influenced by nutrient omission. While total number of tillers and fertile tillers were not influenced by the nutrient omission. The highest biomass yield (7289 Kgha^{-1}) was obtained from the application of 30 Kgha^{-1} S with recommended NP) whereas the lowest (3316 Kgha^{-1}) biomass yield was obtained from the control. The highest grain yield (2001.9 Kgha^{-1}) was recorded from the recommended NP (120 and 68.7 P_2O_5 Kgha^{-1}) with the grain yield increment by 97% compared to N omitted treatment and by 97.3% compared with the control. But application of all nutrients has resulted in grain yield penalty of 9% compared with recommended NP. The result indicated that N and P are the major yield limiting nutrients and their application can sufficiently increase tef yield in the study area. This was justified by the fact that 89.6% of the yield increment was recorded from the application of N nutrients followed by 6.6% yield increment from the application of P and 2.5% yield increment from the application of S respectively. The Additive Main effect and Multiplicative Interaction (AMMI) analysis also indicated that; S omitted, application of S at 30 Kgha^{-1} with recommended NP, and P omitted treatment were the most stable treatment and showed wider adaptation over the tested sites. Whereas, B omitted, N omitted and control treatment were identified as the non-stable treatment and need further investigation. The result also indicated that NP>All-K > All-S >NP+S2 > All-B >All and All-Zn were identified as highest performing treatments across eight environments. Therefore, N and P are the major yield limiting nutrients for tef production in the study area.

Key words: *balanced, nutrient, omission, trial, wheat*

Introduction

Tef is a cereal crop and the local people's principal food crop in Ethiopia, while tef straw is favored as livestock fodder (Assefa *et al*., 2011). Tef is originated and extensively cultivated in Ethiopia (Assefa, 2003; Vavilov, 1951; CSA, 2019). It is a key cereal crop that provides a living for the majority of smallholder farmers, as well as a strategic crop with the potential to boost smallholder agricultural commercialization and food security in Ethiopia (Gidelew *et al*., 2022). The majority of small-scale farmers in Ethiopia prefers tef because it is the most adaptable to a wide range of environmental conditions (Gelaw and Qureshi, 2020). In comparison to other grains, the crop well grows in marginal locations and is drought tolerant. The national productivity of tef is very low 1.8 t/ hectare (CSA, 2019).

Tef production in Ethiopia faces several challenges, such as low yield, poor quality, pest and disease infestation, climate change, lack of improved varieties, inadequate input supply, and limited market access (Hailu *et al*., 2017; Tadele and Tewabe, 2021) all contributed to low productivity of tef. The low tef productivity in Ethiopia's are primarily due to continuous cropping, repeated tillage, insufficient organic fertilizer addition, complete removal of crop residues, and little or no compensation for removal through the application of external inputs (Karltun *et al*., 2013). There are also wide variations in grain yields among tef farms as a result of differences in the practices used to manage crops and in soil fertility (Fikadu *et al*., 2019). Even when traditional plant husbandry farmers used superior tef cultivars, yields were significantly lower than potential due to inadequate crop and soil management methods. In most cases, farmers that plant improved cultivars and adopt enhanced management approaches such as row sowing versus spreading and proper N and P fertilizer treatment earn the highest yields. Differences in planting rate, N and P application rates, and weed control strategies are all key contributors to tef output variability among farms and locales in Ethiopia (Vandercasteelen *et al*., 2014; Fekremariam *et al*., 2020).

Low fertilizer application by Ethiopian farmers is a challenge that affects the agricultural productivity and food security of the country. This is mainly because of lack of knowledge and extension services on the optimal type, rate, and timing of fertilizer application for different crops and soils. Therefore, Developing and disseminating location-specific fertilizer recommendations based on soil testing and crop response, and providing training and extension services to farmers on the best practices of fertilizer use is very important to increase tef productivity in Ethiopia. In this regard, nutrient omission trials are conducted to identify the nutrient deficiencies and imbalances that limit crop production in different soils and regions (Nziguheba *et al*., 2009). By omitting one or more nutrients from the fertilizer application, the trials can reveal the effects of each nutrient on the crop growth, yield, and quality. The results of the trials can help to develop and disseminate location-specific fertilizer recommendations based on soil testing and crop response, and to improve the efficiency and profitability of fertilizer use (Epée and Paul, 2018; Nziguheba *et al*., 2009; Singh *et al*., 2020; YADAV *et al*., 2020; Rawal *et al*., 2017).

Nutrient omission trial is a technique that is used to estimate fertilizer requirements and identify nutrient limitations for crops. It involves applying adequate amounts of all nutrients except for the nutrient of interest, which is omitted. The yield gap between the target yield and the yield in the omission plot is then used to calculate fertilizer requirements (YESHIBIR, 2023; Abebe *et al*., 2018; Kumar *et a* ., 2018). Nutrient omission trial is important for wheat crop because it can help to: determine the optimal rate and time of Nitrogen, Phosphorus, and Potassium fertilizer application for wheat, which are the three key nutrients that primarily limit crop productivity, identify the variability in soil fertility and crop response to fertilizers across different fields and regions, and develop site-specific fertilizer recommendations that can suit the local conditions, enhance the efficiency and profitability of fertilizer use, and reduce the environmental and economic costs of over- or under-fertilization (Kumar *et al*., 2012)

Therefore, the objective of this experiment was to determine and prioritize the most important yield limiting nutrients and to investigate the indigenous soil supply of macro- and micronutrients for tef production in the study area.

Materials and Methods

Description of the study area: Siyadebrina Wayu district is located in the North Shewa zone of Amhara National Regional State (ANRS), Ethiopia. The district is located 175 kilometers from Addis Ababa, the capital city of Ethiopia. It is precisely placed between 90 42′ and 90 53′ N and 390 08′ and 390 17′ E with an elevation ranging from 2705 to 1260 masl Siyadebrina Wayu district is characterized by the highland (Dega) agro-ecological zone. It receives rainfall ranging from 735 to 1187 mm and experiences average annual minimum and maximum annual temperatures of e 10 ◦C to 22 ◦C respectively. The population is mostly dependent on mixed farming systems. The, major crops grown in the district include: wheat (*Triticum Aestivum),* tef (*Eragrostis tef),* faba bean (*vicia faba*), and lentil (*Lens culinaris)*. However, the district faces several production challenges, such as: climate variability and change, which affect the rainfall patterns, temperature, and evapotranspiration, and cause droughts, floods, pests, and diseases, land degradation and soil erosion, which reduce the soil fertility, water holding capacity, and crop productivity, low adoption of improved agricultural technologies and practices, such as improved seeds, fertilizers, irrigation, and climate-smart agriculture, due to lack of access, awareness, skills, and resources, and poor market access and infrastructure, which limit the farmers' ability to sell their products and obtain inputs and services (Kifle *et al*., 2023). The irregular nature of rainfall has been a severe challenge in the farming community's livelihood in recent decades. According to a research paper by Tekeste Kifle *et al*., 2022, the major soil types in Siyadebrina Wayu district are Vertisols, Nitosols, and Cambisols. Farmer's practice drainage of excess water using BBF (broad bed and furrow) for most crops except tef.

Treatments and Experimental Design: The experiment was conducted in Siyadebirna Wayu district on a total of eight farmers' field in 2021. The treatments were arranged in a randomized complete block design (RCBD) with three replications. The experiment was designed in such a way that the effect of each independent nutrient is quantified and should be compared with the recommended NP (120 $Kgha^{-1}$ N and 68.7 $Kgha^{-1}$ P_2O_5) and control with no fertilizer. In the omission of one nutrient, all other nutrients were applied at the rate of 120 $Kgha^{-1}$ N, 68.7 $Kgha^{-1}$ P_2O_5, 60 $Kgha^{-1}$ K_2O, 10.5 $Kgha^{-1}$ S, 5 $Kgha^{-1}$ Zn and 1 $Kgha^{-1}$ B. The effect of S nutrient application also was quantified by two ways; by omitting the S (10 $Kgha^{-1}$ S) and by increasing the S level (to 30 $Kgha^{-1}$) with recommended NP rate. The treatment includes 10 treatments (Table 1).

Table 1. Treatment set up, description and nutrient application rate

			Applied nutrients ($Kgha^{-1}$)					
Treatment		Description	N	P_20_5	K_20	S	Zn	B
NPKS ZnB	All	Application of all nutrients to determine the attainable yield with application of balanced nutrient	120	68.7	60	10.5	5	1
NPKS Zn	All - B	Application of all nutrient except B to identify the soil indigenous supply capacity of B	120	68.7	60	10.5	5	0
NPKS B	All - Zn	Application of all nutrient except Zn to identify the soil indigenous supply capacity of Zn	120	68.7	60	10.5	0	1
NPK ZnB	All - S1	Application of all nutrient except S (10.5 Kg) to identify the soil indigenous supply capacity of S	120	68.7	60	0	5	

Nitrogen was applied at tillering stage of the crop. Two weeding's were performed. Harvesting was done manually starting from the second week of December to end of December 2022.

Data Collection: All agronomic data were collected following the standard procedures. Effective/fertile tillers were recorded per plant at maturity by counting all fertile tiller having head from 10 randomly selected plants in each plots. Plant height (cm) was measured at maturity from the ground to the tip of the spike excluding the awns from 10 randomly selected main tillers from each plot. Spike length (cm) was also determined from randomly selected 10 plants at maturity stage by measuring the spike of effective tiller from the bottom of the spike to the tip of the spike by excluding the awns. In addition, above ground biomass from the net plot area was harvested from the ground level and sun dried until constant weight was achieved and then expressed in $Kgha^{-1}$. While grain yield ($Kgha^{-1}$) was determined after separating the grains from the straws by threshing manually.

Harvest index (HI) (%) was calculated as the ratio of grain yield to the above ground biomass yield, expressed as a percentage and calculated with the following formula

HI= ————————*100

Where; HI = harvest index

Agronomic efficiency of the applied nutrient was also determined by subtracting the yield of all minus nutrient in target from the yield of all and then divide this result by nutrient application rate. For instance, for determining the N agronomic efficiency, we can subtract the yield of All-N from the yield of All. Then divide this by the N application rate. To determine P agronomic efficiency, the yield from All-P was subtracted from All and then the result is divided by the P application rate. To determine the K agronomic efficiently, the yield from All-K was subtracted from the yield of All and then the result is divided by K application rate. To determine the S agronomic efficiently, the yield from All-S was subtracted from the yield of All and then the result is divided by S application rate. The same procedure was applied for Zn and B agronomic efficiency.

AE= —————————

Where AE= agronomic efficiency

Cation exchange capacity of (CEC) of both districts is also rated as high. The soil analysis result also indicated that the soil available Phosphorus (P) and Boron (B) contents of the experimental sites were rated as low.

Table 2. Soil-physico-chemical properties of the soils of the experimental sites (mean of 8 sites)

Parameters	Range	Mean Value	Rating	References
pH 1:2.5 (H_2O)	5.88-7.2	6.5	Slightly acidic	Tekalign (1991)
Total N (%)	0.05-0.12	0.08	low	Tekalign (1991)
Avail. P (ppm)	8.9-21.6	13.40	Moderate	Olsen (1954)
Excha. K (cmol Kg^{-1})	1.07-1.32	1.19	High	FAO (2006)
S(ppm)	0.25-0.77	0.47	Very low	Bashour and Sayegh (20
B(ppm)	0.5-1	0.75	Low	Jones and Benton (2003)
Excha. Na (cmol Kg^{-1})	0.25-0.67	0.42	Moderate	FAO(2006)
Ca(cmol Kg^{-1})	19.36-24.2	21.76	high to very high	FAO(2006)
Mg(cmol Kg^{-1})	3.1-8.94	4.68	High	FAO(2006)
CEC(cmol Kg^{-1})	20-44	28.06	High	Landon (1991)
EC (1:2.5 suspension) (dS m^{-1})	0.04-0.09	0.07	Non saline	Horneck *et al.*, (2011)
Organic carbon (%)	0.52-1.5	0.96	low	Tekalign (1991)
Sand (%)	10-32	13.00	8.8	
Silt (%)	11-21	13.75	17	
Clay (%)	54-78	73.25	74.3	
Textural class		Clay		

Plant Height: The analysis of variance (ANOVA) showed that tef plant height significantly responded to nutrient omission (Table 3). On average, application of 30 Kg S with recommended NP had the tallest plant height (82.6 cm) while N omitted treatmenthad significantly the shortest plant height (40.5 cm). The lowest plant height observed from the N omitted plot was found statistically similar with the control without any nutrient application. Indicating that application of other nutrient irrespective of N does not bring any improvement in plant height (Table 4). This mainly because N application can increase plant height in tef by stimulating the production of cell division and elongation hormones, such as auxins and cytokinins, and enhancing the photosynthetic capacity and biomass accumulation of the plant. The result indicated that application of N nutrienthad only influence plant height. Similar result were reported by different authors for the same crops in Ethiopia (Beamlaku *et al*., 2022; Tamirat; 2019; Haftamu *et al*., 2009; Desta *et al*., 2021; Okubay *et al*., 2014). This might be attributed to the fact that N normally promotes vegetative development in tef, resulting in taller plants with longer panicles. Nevertheless, omission of P, K, S, Zn and B didn't show any role in determining plant height of tef. Plant height of tef recorded from application of all nutrients was even lower than the recommended NP rate.

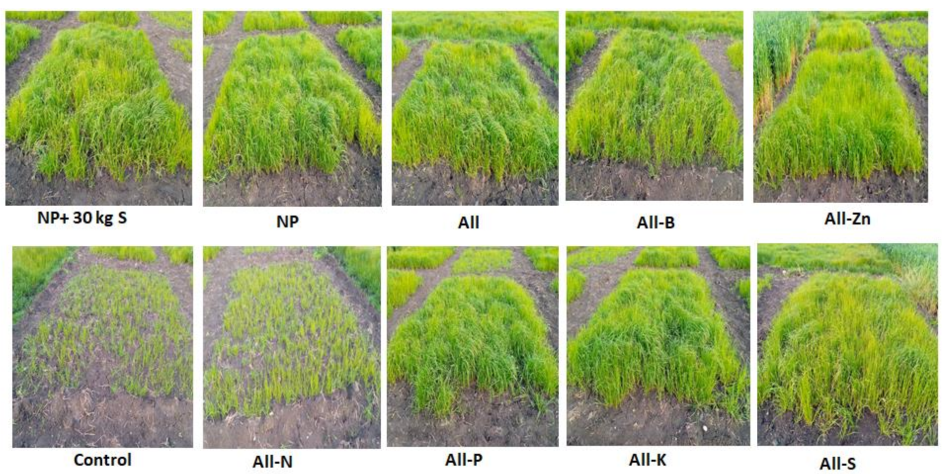


Figure 1. Treatment performance during Vegetative growth

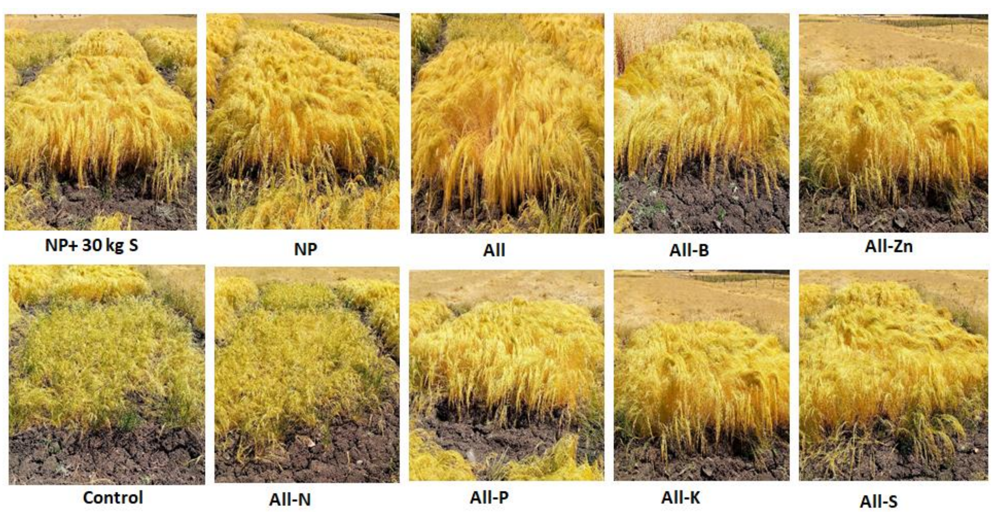


Figure 2. Treatment performance during heading

Table 3. ANOVA for the effect nutrient omission on wheat yield and yield related parameters

Source	DF	Mean square value						
		PH *	PL	TT	FT	BY	GY	HI
Site	7	1467.2***	137.8***	32***	11.8***	57052809.7***	4350869***	0.019***
Rep	2	145.2*	11.8ns	2.89ns	1.2ns	239439.7ns	80608.6ns	0.0031*
Nutrient	9	5978.4***	493.1***	0.7ns	0.3ns	51907625.0***	3300193***	0.0034***
Error	221	40.01	4.559	0.402	0.33	752067	74038.96	0.00083
Total	239							
R-Square		0.88	0.84	0.52	0.54	0.84	0.79	0.48
CV		8.9	7.8	14.7	13.5	14.2	16	10.1
Root MSE		6.33	2.14	0.63	0.58	867.22	272.1	0.029
Mean Value		71.5	27.4	4.3	4.3	6102.2	1705.5	0.28
LSD (0.05)		3.60	1.21	ns	ns	493.4	154.8	0.016

PH= plant height (cm), PL= panicle length (cm), TT= total tiller, FT= Fertile tiller, BY= biomass yield (Kgha^{-1}), GY= grain yield (Kgha^{-1}), HI= harvest index, *, **, * and NS = significant at >1, 1%, 5%*

Table 4. Effect of Nutrient omission treatment on yield related parameters of tef

Nutrient	Plant height (cm)	Panicle length (cm)	Total tiller	Fertile tiller	Harvest Index
NP+S2	82.6^{a}	30.8^{a}	4.4	4.4	0.26^{d}
All-K	80.9^{ba}	30^{ba}	4.4	4.4	0.29^{bac}
NP	79.6^{bac}	29^{b}	4.3	4.3	0.29^{bac}
All-P	78.4^{bc}	29.6^{ba}			

improved the seed set and grain yield. Phosphorus and Sulphur also improved the nutrient availability and the soil fertility, which supported the growth and development of tef plants (Ketema and Abdisa, 2021; Tamirat and Tilahun, 2020).

Number of Tiller per Plant: The analysis of variance (ANOVA) showed that neither total number of tillers nor number of fertile tillers wasn't significantly influenced by nutrient omission (Table 3). The result indicates that, irrespective of the nutrient applied the entire tillers were found fertile.

Biomass Yield: The analysis of variance (ANOVA) showed that biomass yield significantly influenced by nutrient omission treatment and across sites (Table 3). The highest biomass yield (7289 $Kgha^{-1}$) was obtained from the application of 30 $Kgha^{-1}$ S with recommended NP whereas the lowest biomass yield (3316 $Kgha^{-1}$) was from the control plot (Table 5). The biomass yield advantage of this treatment over the recommended NP was 4.1% (285 $Kgha^{-1}$) and 119.8% (3973 $Kgha^{-1}$) over the control. While the biomass yield from this treatment was at par with omission of P, S, Zn and B. Indicating that omission of P, S, Zn and B were equal importance in determining biomass yield. Compared with recommended NP, S omitted treatment, and application of all nutrients, application of 30 $Kgha^{-1}$ S with recommended NP increased biomass yield by 4.1% (285 $Kgha^{-1}$), 10.1% (671 $Kgha^{-1}$), and by 8.6% (577 $Kgha^{-1}$) (Table 5). The result indicated that irrespective of N nutrient, application of other nutrient does not bring any significant biomass improvement. This was justified by the fact that only 1.8% (60 $Kgha^{-1}$) yield improvement with application of 68.7 $Kgha^{-1}$ P_2O_5, 60 $Kgha^{-1}$ K_2O, 10.5 $Kgha^{-1}$ S, 5 $Kgha^{-1}$ Zn and 1 $Kgha^{-1}$ B.

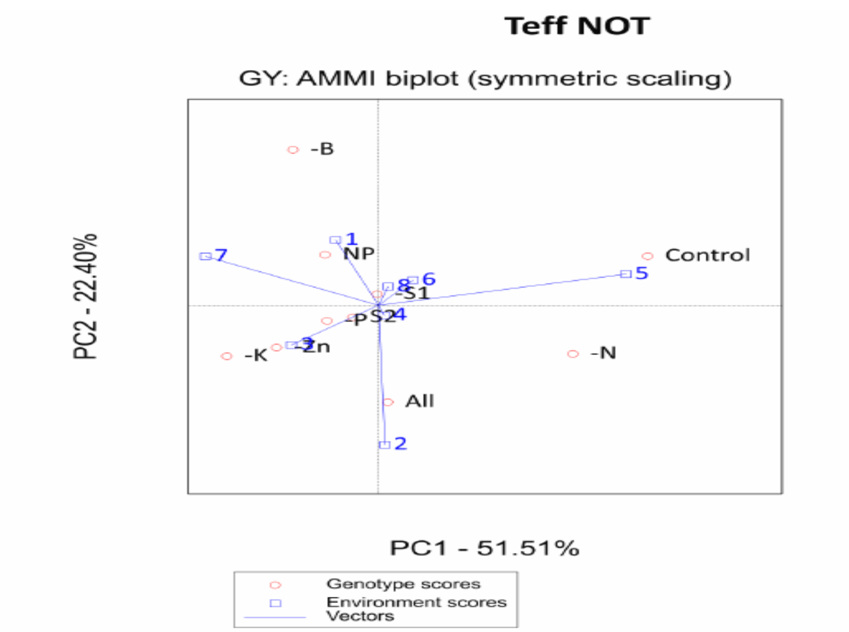
Grain Yield: Grain yield is the outcome of several complex morphological and physiological processes that occur throughout crop growth and development (Khan *et al*., 2008). The analysis of variance revealed that tef grain yield was significantly influenced by nutrient omission (Table 3). The highest grain yield (2001.9 $Kgha^{-1}$) was recorded from the application of recommended NP and ithad 97% yield advantage compared with N omitted treatment and 97.3% yield advantage compared with the control (Table 5). The grain yield obtained from the other treatments was at par with the yield obtained from recommended NP. However, application of all nutrients has resulted in grain yield penalty by 9% (168 $Kgha^{-1}$) compared with application of RNP indicating that application of N and P nutrients was sufficient for this crop in the study area. This was justified by the fact that 89.6% of the yield increment was recorded from the application of N nutrients (Table 7). This was followed by 6.6% and 2.5% yield increment with application of P and Zn nutrients (Table 5).

Application of Nitrogen and Phosphorus fertilizer increased tef yield by enhancing the vegetative growth of the plants, resulting in taller plants with more tillers and longer panicles. It also increased the post-anthesis Nitrogen uptake and translocation from the vegetative organs to the grains, which improved the seed set and grain filling (Chala *et al*., 2022). Similarly, Beamlaku *et al*., (2022) reported that omission of N reduced tef grain yield by 81.6%, 96.5%, and 58.0% on-station, on-farm, and pot experiments, respectively as compared to the applied NP nutrients. The positive effect of N and P nutrients in increasing crop yield was reported by different authors (Fekremariam *et al*., 2022; Mirutse *et al.,* 2009; Beamlaku *et al*., 2022; Kumar *et al*., 2018; Rawal *et al*., 2018; Tadele *et al*., 2018; Tesfaye *et al*., 2019, Getahun *et al*., 2018; Kefyalew *et al*., 2012; Abay *et al*., 2011; Giday *et al.,* 2014; Bekalu and Tenaw, 2015). The result also indicated that application of other nutrients doesn't bring any significant yield improvement on tef. Nevertheless, Bereket *et al*. (2011), reported that On-farm application of Zn fertilizer at a rate of 8 $Kgha^{-1}$ Zn increased tef grain and straw yields by 14% and 15% on average, respectively, which could be economically profitable. Eyasu *et al*., (2022) also reported that application of K fertilizer increase tef yield by 20% compared with the control from the on-farm experiment conducted in four districts of the central highlands of Ethiopia (Suluta, Mulo, Moretina Jiru, and Bereh). Similarly, Demiss *et al*., 2019 and Mulugeta *et al*., (2020) reported that K fertilizer application significantly affected tef grain and straw yield in 67% of the researched 18 locations in central Ethiopia.

Grain yield data were subjected to Additive Main effect and Multiplicative Interaction (AMMI) analysis to determine the stability of the nutrient across different environment (sites). This is actually, because the mean grain yield obtained in the normal analysis of variance (ANOVA) procedure might be skewed because of the highest yield observed from some sites. Based on the result obtained, S omitted, application of S at 30 $Kgha^{-1}$ with recommended NP, and P omitted treatment were the most stable treatments and showed wider adaptation over the tested sites (Figure 3). Zn omitted, recommended NP, K omitted and application of all nutrients were moderately stable across the tested environment (Figure 3). Whereas, B omitted, N omitted and control treatment were identified as the non-stable treatment and need further investigation (Figure 6). The highest yielding treatments based on AMMI selection were also performed for the eight sites (Table 6). Based on this ranking, treatments having highest performance were found to be; NP>All-K > All-S >NP+S2 > All-B >All and All-Zn (Table 4).

Table 5. Effect of nutrient omission treatment on biomass and grain yield of tef

Nutrient	Biomass yield (Kgha^{-1})	Grain yield (Kgha^{-1})
NP+S2	7288.9^{a}	1906.9^{bac}
All-K	6938.3^{ba}	1969.3^{ba}
NP	7004^{ba}	2001.9^{a}
All-P	6574.5^{b}	1773.8^{c}
All-Zn	6573.1^{b}	1810.6^{c}
All-B	6621.1^{b}	1813^{c}
All-S1	6617.8^{b}	1914.9^{bac}
All	6711.6^{b}	1833.7^{bc}
Control	3316^{c}	1014.8^{d}
All-N	3376.3^{c}	1016.3^{d}
LSD (0.05)	493.37	154.8



. Stability of nutrient omission treatment

Site	MeanGY*(Kgha^{-1})	IPC score	Treatment ranking			
			1st	2nd	3rd	4th
1	1998	4.132	NP	All-B	All-K	All-S1
2	1837	-0.603	All-K	All	S2	All-Zn
3	2206	8.406	All-K	NP	S2	All-S1
4	1960	-0.526	NP	All-K	All-S1	S2
5	1160	-23.888	NP	All-S1	S2	All
6	1250	-3.326	NP	All-S1	All-K	S2
7	1811	16.731	All-K	NP	All-B	S2
8	1422	-0.925	NP	All-K	All-S1	S2

**GY= grain yield*

Table 7. Relative importance of nutrient for biomass and grain yield of wheat

Treatment	GY(Kgha^{-1})	BY(Kgha^{-1})	Relative importance of nutrients	Increase (Kgha^{-1})		Relative increase (%)	
				GY*	BY	GY	BY
Control	1014.8	3316.0					
RNP	2001.9	7004.0					
RNP+S2	1906.9	7288.9					
All	1833.7	6711.6	All=(All-Control)	818.9	3396		
All-N	1016.3	3376.3	N=(All-All-N)	817.4	3335	89.6	88
All-P	1773.8	6574.5	P=(All-All-P)	59.9	137	6.6	4
All-K	1969.3	6938.3	K=(All-All-K)	-135.6	-227		
All-S1	1914.9	6617.8	S1=(All-All-S1)	-81.2	94		2
All-Zn	1810.6	6573.1	Zn=(All-All-Zn)	23.1	139	2.5	4
All-B	1813	6621.1	B=(All-All-B)	20.7	91		2

**GY= grain yield; SY= straw yield*

Agronomic Efficiency: Agronomic efficiency is the amount of additional yield obtained for each additional Kg of nutrient applied (Fageria and Baligar, 2001). Agronomic efficiency could be used to characterize the nutrient effect (Dobermann, 2007). The highest (21 KgKgha^{-1}) and lowest (-5 KgKg^{-1}) agronomic efficiency were recorded with application of B and S nutrient respectively. Application of N, P, Zn and K nutrient also resulted in agronomic efficiency of 7 KgKgha^{-1}, 2 KgKg^{-1}, and 5 KgKg^{-1}, and -3 KgKg^{-1}, respectively (Figure 4). Indicating that B, N, Zn and P were the most important nutrient in increasing agronomic efficiency of wheat. Nevertheless, application of K and S resulted in a negative agronomic efficiency (Figure 8). Negative agronomic efficiency for the applied nutrient is an indication that the nutrient application rate under consideration is too high, too low, or not suitable for the crop or soil conditions (Vanlauwe *et al*., 2011). It can also indicate that the fertilizer is lost to the environment due to leaching, runoff, volatilization, or denitrification (Brentrup & Pallière, 2010). Negative agronomic efficiency of applied fertilizer is undesirable for both economic and environmental reasons, as it implies a waste of resources and a potential source of pollution (Awada & Phillips, 2021). To avoid negative agronomic efficiency of applied fertilizer, it is important to apply the right type, amount, and timing of fertilizer for the specific crop and soil situation.

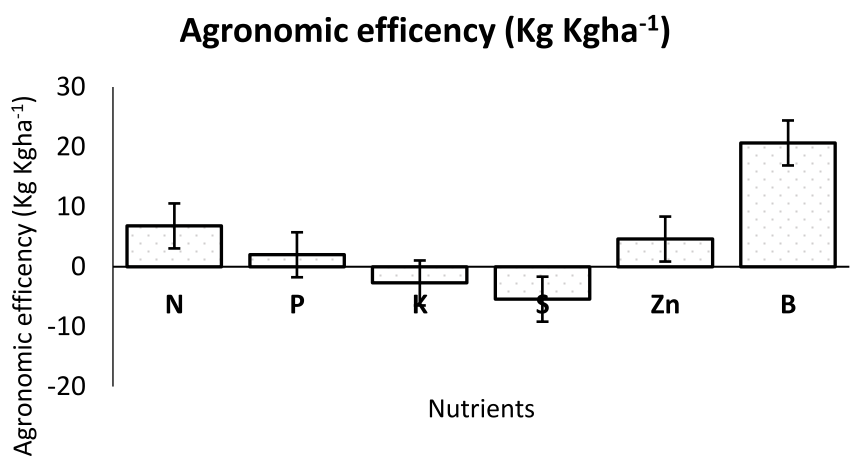


Figure 4. Agronomic efficiency of wheat for application of different nutrient

Correlation analysis: The correlation analysis result depicted that, grain yield was positively and significantly correlated with plant height (R^2=0.77***). It means that there is a strong and reliable relationship between the two traits, and that higher plants tend to produce more grains. This could be because taller plants have more biomass, more tillers, and longer panicles, which are all associated with higher grain yield (Jifar *et al*., 2015; Teklu and Hailu, 2005). Grain yield also positively and significantly correlated with biomass yield (R^2=0.92***). This is because plants that produce more biomass tend to produce more grains. This could be because higher biomass indicates higher photosynthesis, which provides more carbohydrates for grain filling. It could also be because higher biomass reflects higher tillering, which increases the number of panicles and grains per plant (Bayable *et al*., 2021; Teklu and Hailu, 2005). This means there is a strong and reliable relationship between the two traits, and that plants thathave longer panicles tend to produce more grains. This could be because longer panicles have more spikelets and grains, and also because longer panicles indicate higher vegetative growth and biomass, which provide more carbohydrates for grain filling (Woldeyohannes *et al*., 2022; Merchuk-Ovnat *et al.*, 2020). Similarly, grain yield of tef significantly and positively correlated with fertile tiller (R^2=0.18**), and total tiller (R^2=0.18**). Similarly, biomass yield were positively and significantly correlated with panicle length (R^2=0.85***) and plant height (R^2=0.87***) (Figure 5). Beamlaku et *al.*, (2022) reported that grain yield of tef positively and significantly correlated with plant height, panicle length and biomass yield (Figure 5).

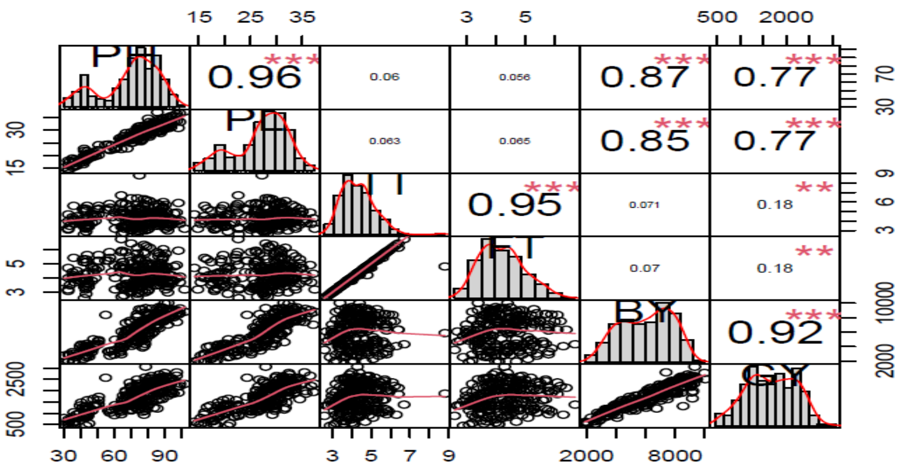


Figure5. Correlation among agronomic, yield related and yield data

Conclusion and Recommendation

Appropriate fertilization based on actual limiting nutrients and crop requirements is economic and judicious for sustainable crop production. Nutrient omission trial is an excellent tool for nutrient assessment because it can indicate the most limiting nutrient and the order of limitation. The result indicated that most of the measured parameters were responded for nutrient omission treatment. Higher mean grain yield of 2001.9 Kgha^{-1} and biomass yield of 7289 Kgha^{-1} tef were recorded with application of recommended NP and from application of 30 Kgha^{-1} S with recommended NP, respectively. The lowest mean grain (1014.8 Kgha^{-1}) and biomass (3316 Kgha^{-1}) yield observed from the control plot without any nutrient applications. The result also indicated that 89.6% and 88% of the grain and biomass yield improvement of tef was determined by N nutrient applications. This was followed by 6.6% and 4% yield improvement with P applications. Therefore, only N and P nutrients were identified as the most yield limiting nutrients for the test crop.

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