I) Soil Fertility and Management of Problematic Soils

1. Yield-Limiting Nutrients for Bread Wheat Production on the Vertisols of Central Highlands of Ethiopia.

Beza Shewangizaw*, Yalemegena Gete, Shawel Assefa, Kenzemed Kassie, Lisanu Getaneh, Getaneh Shegaw, Getachew Lema and Genet Taye

Debre Birhan Agricultural Research Center, P.O.Box 112, Debre Birhan, Ethiopia

*Correspondence: bezashewangezaw@gmail.com; ORCID: https://orcid.org/0000-0002-1888-5420

Abstract

Wheat production and productivity in Ethiopia are influenced by various factors, with nutrient availability being one of the most critical in the central highlands. An experiment was conducted in the Moretina Jiru fields to identify the most important yield-limiting nutrients for bread wheat production. The treatments were designed to quantify the contribution of individual nutrients to yield increase. The study included ten treatments: NPKSZnB (All), NPKSZn (All-B), NPKSB (All-Zn), NPKZnB (All-S), NPSZnB (All-K), NKSZnB (All-P), PKSZnB (All-N), NP (Recommended NP), and a control (without nutrients). The treatments were arranged in a randomized complete block design with three replications at each field. Composite soil samples were collected before planting from each site at a depth of 0 20 cm for analysis of soil physicochemical properties. The results indicated deficits in Nitrogen (N), Sulphur (S), and Phosphorus (P) across all study sites. The study found significant differences in all measured parameters, including plant height, spike length, fertile tillers, biomass yield, grain yield, and harvest index, between treatments. In the Moretina Jiru district, the highest biomass (11,474 kg/ha) and grain yield (5,073 kg/ha) were achieved with the combined application of 30 kg S and recommended NP. This treatment increased biomass and grain yield by 333% (8,827 kg/ha) and 350% (3,945 kg/ha) compared to the control (without nutrient application). The lowest biomass and grain yield were observed in the control plot, which was statistically similar to the N-omitted plot. Nitrogen, Sulphur, and Phosphorus were identified as the limiting nutrients for biomass and grain yield of wheat. In the Mojana Wodera district, the highest biomass and grain yield were observed with the application of all treatments, which increased biomass yield by 240% (7,020 kg/ha), 184% (6,446 kg/ha), and 18% (1,540 kg/ha) compared to the control, N-omitted, and recommended NP treatments, respectively. The highest biomass yield (9,464 kg/ha) was observed in the Zn-omitted plot, followed by the application of all treatments. Zn omission increased biomass yield by 240% (7,020 kg/ha), 184% (6,446 kg/ha), and 18% (1,540 kg/ha) compared to the N-omitted treatment, control treatment, and recommended NP, respectively. The highest grain yield (4,009.6 kg/ha) and lowest grain yield (945.3 kg/ha) were obtained from the application of all nutrients *and the control treatment, respectively. Concerning agronomic efficiency, the highest (71 kg/ha) was recorded from the application of micronutrients (B and Zn), followed by P application. Nitrogen, Phosphorus, and Sulphur were the most yield-limiting nutrients for this district as well. Therefore, N, P, and S are the most yield-limiting nutrients for the production of bread wheat in the study areas. The application of NPS-containing fertilizers at biologically and economically optimal rates is recommended for the optimum production of bread wheat in the study areas.*

Keywords: Bread wheat, nutrient omission, yield limiting nutrients, Vertisols

Introduction

Wheat (*Triticum aestivum* L.) is a globally produced and sold cereal crop that accounts for 15% of total cereal crops area coverage globally (Kiss, 2011). It ranks second among the world's most important cereal crops after rice (Asadallah, 2014; Falola *et al*., 2017). Wheat accounts for around 17% of total grain production in Ethiopia, ranking it third after tef and maize (CSA 2021). Ethiopia's yearly production of wheat is about 5.8 million tons, with a mean productivity of 3 tha^{-1} (CSA 2021), which is significantly lower than the crop's possible yield of up to 5 tha^{-1} (Zegeye *et al*., 2020). Wheat is one of the most widely adapted crops, growing in a variety of altitudes (Tadesse, 2019) and produced in rain fed and irrigated production system. Wheat production and productivity in Ethiopia are influenced by different factors. Understanding and prioritizing the most important factors is the first steps in increasing wheat productivity and production. Lack of accurate information about soil nutrient requirements coupled with limited access to appropriate fertilizers could lead to mismatch between soil nutrient requirements and fertilizer applications (Kibrom *et al*., 2021).

Fertilizer research in Ethiopia began in the 1960s, after a soil survey expedition in the late 1950s revealed widespread deficiency of Nitrogen (N) and Phosphorus (P) in the soils. The initial research focused on the response of cereals, such as tef, wheat, and maize, to the application of N and P fertilizers. In the early 1970s, a blanket recommendation of 64 Kgha^{-1} N and 20 Kgha^{-1} P was made for all crops and soil types, which was applied in the form of di-ammonium phosphate and urea (Teklu *et al*., 2022; Abdulkadir *et al*., 2017). However, this recommendation was not effective, as only 30-40% of the farmers used fertilizers at a rate less than recommended, and the cereal yields increased only 10% despite a five-fold increase in fertilizer application since the 1980s. This was due to limited supply, high prices, and low and declining crop response to fertilizers. Moreover, the blanket recommendation did not account for the variability in soil types, climate, and crops ((Teklu *et al*., 2022). Therefore, in the 1980s, more comprehensive and site-specific research was conducted across agro-ecological and edaphic spectrum, which recommended 30-138 Kgha^{-1} N and 0-50 Kgha^{-1} P, depending on the crop and soil type. In the 1990s, research on the integrated use of inorganic and organic sources of fertilizers was initiated, which resulted in increased yield and better economic benefits. However, these recommendations were not widely adopted or disseminated by the national agricultural extension system (Teklu *et al*., 2022). In 2011, a new soil survey expedition was launched, which mapped the soil nutrient status using literature-based critical limits. The maps showed the deficiency of N, P, Potassium, Sulphur, Zinc, and Boron across the surveyed areas. The recent soil fertility map of the Amhara national regional state developed by MoANR and ATA indicates that in addition to the conventional N and P containing fertilizers and 96% of the soil are deficient in macro (N, P, K and S) and micro nutrients (Zn, B, Cu and Fe) (EthioSIS, 2016). Thereafter, the interest in applying other nutrients other than NP nutrient substantially increased. For this purpose, on station and on farm trial were established to evaluate different blend fertilizers across different parts of Ethiopia (Teklu *et al.*, 2022; Bizuwork and Yibekal, 2020; Hiwot, 2012; Abdurahman *et al*., 2021; Ishete and Tana, 2019; Tilahun and Tamado, 2019; Bizuwork and Yibekal, 2020; Tadele *et al*., 2018). However, this trial ends up with a range of outcomes. Some research report indicated that application of other nutrients for instance S nutrient increase crop yield (Shawel *et al.*, 2021, Assefa, 2016, Almaz 2021, Ayele *et al*., 2020; Sofonyas *et al*., 2022). In contrary, other report indicated that the non-significant impact of this nutrient (K, Zn and B) on wheat yield (Tadele *et al*., 2018, Liben *et al*., 2020). There is also a controversy result on nutrient like K. Some report indicated that application of K increased crop yield (Hagos *et al*., 2017; Yohannes *et al*.,2018; Abiye *et al*., 2004; Hailu *et al*., 2017; Gebrehawariyat *et al*., 2018).

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 al*., 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 wheat production in the study area.

Material and Methods

Description of the Study Area: The experiment was conducted on farmers' field of Moretina Jiru district (8 farmer's field) and Mojana Wodera district (5 farmers field) during the main cropping season in 2021. Moretina Jiru is located in North Shewa Zone of the Amhara Regional State. The area is located 195 km North East of Addis Abeba. Vertisols are the dominant soil type in the areas. The farming system is characterized by mixed crop-livestock. Wheat, tef and sorghum are the most important cereals produced in the districts. The rainfall in the growth period was 1042.76mm. The temperature varies from 5.2°C in November to 28.8°C in June.

Mojana Wodera district is located in the Amhara regional state, North Showa zone, central Ethiopia. The district is located 202 kilometers north of, Addis Abeba, and 72 kilometers north of Debere Brehan town. Ithas an elevation range of 1459-3172 m above sea level and is traditionally separated into three agricultural zones: Dega (28%), Woyna Dega (69%), and kola (3%). Specifically, our experiment was conducted in the Dega agro-ecological zone. The district's yearly rainfall ranges between 800-1000 mm, and the annual temperature ranges from 10-18^{0}C

Treatments Set up and Experimental Design: The experiment was conducted in a randomized complete block design (RCBD) with three replications on total of eight farmers' fields in Moretina Jiru district and five farmers field in Mojana Wodera districts. The experiment is designed in such a way that the effect of each individual nutrient is quantified and should be compared with the recommended NP (167 Kgha^{-1} N and 103.5 Kgha^{-1} P_2O_5) and control (with no fertilizer). While omitting a nutrient, all other nutrients were applied. The rates were: 167 Kgha^{-1} N, 103.5 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 further looked with one more nutrient (30 Kgha^{-1}) with recommended NP rate. The total treatment was 10 (Table 1).

Crop Management: Bread wheat var. Dendea used at the rate of 150 Kgha^{-1}. Planting was by broadcast in July (23-29/2021) in Moretina Jiru and from July 17 to August 6/2021 in Mojana Woderadistrict. The wider gap for planting in Mojana Wodera district is because of planting date difference of distinct soil types (Vertisols and Cambisols). A gross plot size was 12.24m^2 and BBF (broad and bed furrow) with a bed and furrow width of 80 and 40 cm used. The whole amounts of TSP (0–46 P_2O_5-0), KCL (0-0-60 K_2O), $MgS0_4$ (12.9%S), ZnEDTA (10% Zinc), $Na_2B_4O_7.10H_2O$ (11% Boron), and half split of Nitrogen (46 N-0-0) fertilizer were applied at planting. The remaining half split of Nitrogen was topdressed at tillering stage of the crop. Harvesting was made at physical maturity of the crop.

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

NPKSZnB	All	Application of all nutrients to determine the attainable yield with application of balanced nutrient	167	103.5	60	10.5	5	1
NPKSZn	All - B	Application of all nutrient except B to identify the soil indigenous supply capacity of B	167	103.5	60	10.5	5	0
NPKSB	All - Zn	Application of all nutrient except Zn to identify the soil indigenous supply capacity of Zn	167	103.5	60	10.5	0	1
NPKZnB	All -S1	Application of all nutrient except S (10.5 Kg) to identify the soil indigenous supply capacity of S	167	103.5	60	0	5	1
NPSZnB	All - K	Application of all nutrient except K to identify the soil indigenous supply capacity of K	167	103.5	0	10.5	5	1
NKSZnB	All - P	Application of all nutrient except P to identify the soil indigenous supply capacity of P	167	0	60	10.5	5	1
PKSZnB	All-N	Application of all nutrient except N to identify the soil indigenous supply capacity of N	0	103.5	60	10.5	5	1
NP	NP	Application Recommended N and P only for comparison with those treatments.	167	103.5	0	0	0	0
Control	Control	without any nutrient application	0	0	0	0	0	0
NP+30 Kg S	RNP + S2	Application of recommended N, P and S (30 Kgha^{-1}) to identify the response of S over the recommended NP	167	103.5	0	30	0	0

Data Collection: All agronomic data were collected following standard procedures. Effective/fertile tiller were recorded per plant base at maturity stage of the test crop 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) also determined from randomly selected 10 plants at maturity stage of the crop by measuring the spike of effective tiller from the bottom of the spike to the tip of the spike by excluding the awns. Above ground biomass from leaves, systems and seeds from the net plot area was harvested from the ground level and sun dried until constant weight achieved and then expressed in Kgha^{-1}. Grain yield (Kgha^{-1}) was determined after threshing the above ground biomass manually. The grain yield was adjusted to 12.5% moisture content after measuring the grain moisture using moisture tester.

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

$$HI = \frac{\quad}{\quad}$$

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.

$$AE = \frac{\quad}{\quad}$$

Where AE= agronomic efficiency

GYf= grain yield of fertilized plot

GYc = grain yield of unfertilized plot

Soil sample Collection and Analysis: Composite soil samples from a depth of 0-20cm from each site were collected before planting for analysis of soil physicochemical parameters using an augur from 10 spots by walking in a zigzag fashion. After thoroughly mixing the composite samples, 1 kilogram of sub-sample was taken for the analysis. Soil samples were air dried under shed conditions and crushed to pass through a 2 mm mesh sized sieve. The texture of the samples was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The pH of the soil was tested using the pH-water method with 1:2.5 soils to water suspension and measured with pH meter. Wet digestion method was used to determine the OC content of the soil (Walkley and Black, 1934). Total Nitrogen (TN) was determined using the modified micro Kjeldhal method, available P was determined using the Olsen *et al.*, (1954) method, and exchangeable K in the soil was extracted with 1 N NH_4OAc and determined using a flame photometer (Jones, 2001). A spectrophotometer was used to assess soil available Sulphur. CEC was measured after the soil was saturated with 1 N NH_4OAc and displaced with 1 N NaOAc (Chapman, 1965).

Data Analysis: The collected data were subjected to analysis using statistical analysis software (SAS) 9.3 (SAS, 2012). Analysis of variance (ANOVA) was carried out to determine the presence of significant differences among and between treatments. Mean separation of was carried out using the least significant difference (LSD) test at $P \leq 0.05$ levels.

Results and Discussion

Based on the soil analysis of before planting, the soil textural class the study sites were clay. The soil pH of both districts was 6.5. Based on the rating developed by Tekalign (1991), it was rated as slightly acidic (Table 2). The total Nitrogen, organic carbon and available S content of both site also rated as low to very low (Table 2). The soils of both experimental sites of the districts are rated as high in K, Mg. the Cation exchange capacity of (CEC) of both districts are also rated as high. The soil analysis result also indicated that the soil available Phosphorus (P) content was found to be ranged from low to optimum. The available P content of Moretina Jiru are even higher than the P critical developed for the same crops in Vertisols (Beza *et al*., 2020). The Boron (B) content of both districts is rated as low.

Table 2. Mean Soil-Physico chemical properties of the experimental soil

Parameters	Mean Value		Rating	References
	MW	MJ*		
pH 1:2.5 (H2O)	6.9	6.5	Slightly acidic	Tekalign (1991)
Total N (%)	0.09	0.1	low	Tekalign (1991)
Avail. P (ppm)	11.3	17.9	Low-optimum	Olsen (1954)
Excha. K ($cmolKg^{-1}$)	1.15	1		

Therefore, N, S and P nutrient were identified as the major yield limiting nutrients for bread wheat productivity in the study areas. Of course, the response of wheat to N and P nutrient application is well documented for this crop (Adamu, 2018; Melesse, 2017; Getachew *et al*., 2015; Fresew *et al*., 2018).

The result indicated that, grain yield decreased with S omitted treatment and dramatically increased with application of 30 Kg S with recommended NP. Application of recommended NP with 30 Kgha^{-1} S was superior over other treatment in four farmers field (Figure 2). This treatment increase yield from 13% (595 Kgha^{-1}) to 27% (1107 Kgha^{-1}), from 2% (83 Kgha^{-1}) to 19% (1043 Kgha^{-1}), from 267% (3695 Kgha^{-1}) to 485% (4371 Kgha^{-1}) and from 226% (3519 Kgha^{-1}) to 511% (4410 Kgha^{-1}) compared to recommended NP, application of all nutrients with 10.5 Kgha^{-1} of Sulphur, control and N omitted treatment, respectively. Indicating that application of S nutrient is highly required in this district. The increase in grain yield with application of S nutrient was associated with a high N uptake rate and the positive interaction between both nutrients (Fernando *et al*., 2009). Similarly, different authors reported that application of S increased wheat yield (Aulakh, 2003; Kiros and Singh, 2009; Shawel *et al*., 2021; Assefa., 2022; Almaz 2021, Ayele *et al*., 2020; Assefa, 2016)

In Mojana Wodera district the highest (4009.6 Kgha^{-1}) and lowest (945.3 Kgha^{-1}) grain yield were observed from application of all nutrient and control treatment, respectively. The yield difference between the control treatments with other treatment was not consistent across different field and the difference was small in some of the sites (Figure 1). This is also because of the different variability across different farms. In some of the sites, the yield observed with the highest yielding treatment is even lower than the mean yield of all farms. Compared with the control, application of 30 Kg S with recommended NP resulted in the highest yield in two farms followed by application of all nutrients, K omitted and S omitted plot. In this district, 61% of the grain yield of wheat was limited by N followed by P application (26%), Zn application (7%), S application (4%), and B application (Table 6). Similarly, Limin *et al*. (2013) also reported that N was the first nutrient limiting for wheat yield in China, followed by P, and then K. Addition of K nutrient did not bring any significant yield improvement indicating indigenous soil supply of this nutrient is sufficient to at least the current situation.

Table 3. Effect of Nutrient omission treatment on biomass and grain yield of wheat

Treatment	Biomass yield (Kgha^{-1})		Grain yield (Kgha^{-1})	
	MJ	MW	MJ	MW
Control	3016.7^{d*}	2929.7^{c}	1127.9^{d}	945.3^{c}
All-N	2647.6^{d}	3503.3^{c}	1158.7^{d}	1113.6^{c}
All-P	9923.9^{c}	7723.8^{b}	4510.8^{bc}	2771.7^{b}
All-K	10868.6^{ba}	9593.1^{ab}	4716.9^{b}	4000.8^{a}
All-S1	9808.5^{c}	8450.2^{ab}	4372.1^{c}	3815.4^{a}
All-Zn	10924.7^{ba}	9464.1^{ab}	4749^{b}	3656.9^{ab}
All-B	10961.8^{ba}	9408.5^{ab}	4793.4^{ba}	3938.6^{a}
NP	10343.1^{bc}	8409.3^{ab}	4645.4^{bc}	3627.9^{ab}
NP+S2	11474.2^{a}	9393.8^{ab}	5073.1^{a}	3871.3^{a}
All	10565.8^{b}	9949.4^{a}	4757.6^{b}	4009.6^{a}
LSD(0.05)	638.33	1037	305.88	527.7
CV (%)	12.4	20.1	13.5	21.6

$^{*a, b, c}$ Mean value with different letters of superscript with in the column are significantly different (P<0.05), MJ= Moretina Jiru, MW= Mojana Wodera,

Table 4. Relative importance of Nutrient for biomass and grain yield of wheat (Kgha^{-1})

	Biomass yield		Grain yield		Relative importance of Nutrients	Increase (Kgha^{-1})				% Increase			
						BY		GY		BY		GY	
Nutrients	MJ*	MW	MJ	MW		MJ	MW	MJ	MW	MJ	MW	MJ	MW
Control	3017	2930	1128	945									
RNP	10343	8409	4645	3628									
RNP+S2	11474	9394	5073	3871									
All	10566	9949	4758	4010	All=(All-Control)	7549	7020	3630	3064				
All-N	2648	3503	1159	1114	N=(All-All-N)	7918	6446	3599	2896	85	56	84	61
All-P	9924	7724	4511	2772	P=(All-All-P)	642	2225	247	1238	7	19	6	26
All-K	10869	9593	4717	4001	K=(All-All-K)	-303	356	41	9		3	1	
All-S1	9809	8450	4372	3815	S1=(All-All-S1)	757	1499	386	194	8	13	9	4
All-Zn	10925	9464	4749	3657	Zn=(All-All-Zn)	-359	485	9	353		4	0	7
All-B	10962	9409	4793	3939	B=(All-All-B)	-396	541	-36	71		5		1

*MJ= Moretina Jiru district, MW= Mojana Wodera district, BY= biomass yield (Kgha-1), GY= grain yield (Kgha^{-1})

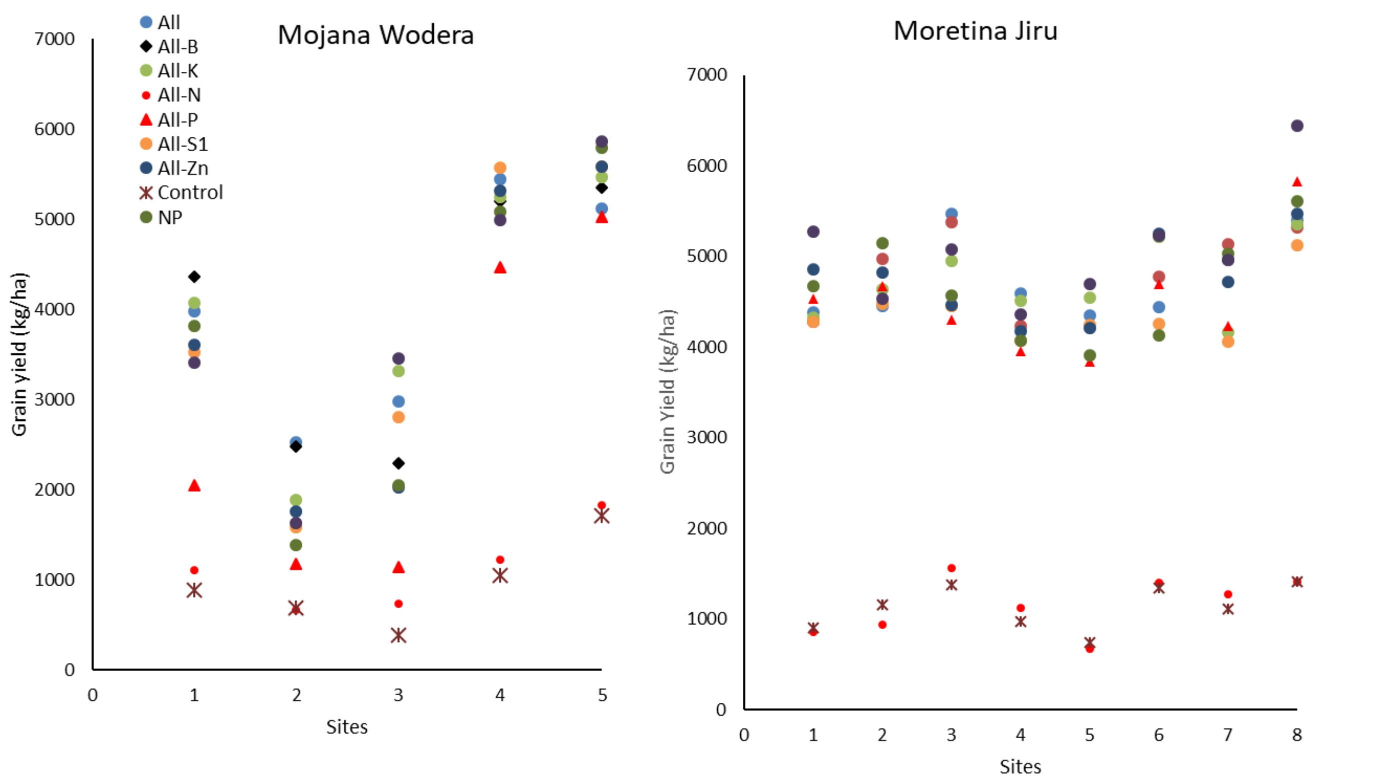

Figure 1. Effect of different nutrient omission treatment compared with the control

Agronomic and Yield Related Parameters: The effect of nutrients omission significantly influenced plant height in both locations (Table 5). In Moretina Jiru district the highest plant height of wheat was recorded from application of 30 Kgha^{-1} S with recommended NP rates. The lowest plant height was recorded from the control. The control treatment was found statistically non-significant with N omitted treatment. Indicating N is the most important nutrient in increasing the plant height. This increase in plant height could be attributed to the fact that N improves plant height by influencing the synthesis of macromolecules (proteins, enzymes, pigments, hormones, and so on) as well as the rate of processes such as photosynthesis on cell division and cell elongation, and ultimately internode length. Boosted N rates in the soil results in greater internode length that increase plant height. N application also improved the total vegetative growth of bread wheat (Saeed *et al*., 2012). In Mojana Wodera district, the highest and lowest plant height was recorded from K omitted and control treatments, respectively. Indicating that the soil K status of the experimental site were found to be sufficient in K. Spike length of wheat also significantly influenced by nutrient omission treatment in both locations (Table 5). The highest spike length in Moretina Jiru district was recorded from application of the recommended NP with 30 Kgha^{-1} S. In Mojana Wodera district, the highest spike length was recorded from K omitted treatment. In both locations, the lowest spike length was recorded from the control treatment and this treatment was found statistically as par with N omitted treatment. Fertile tiller were also counted in each treatment by considering all wheat planthaving head during maturity time. The analysis of variance showed that number of fertile tiller per plant showed significant variation with nutrient omission treatment (Table 3). In both locations, the highest number of fertile spike was recorded from K omitted treatment and the lowest was from the control treatment (Table 5). Indicating that application of this nutrients is not required in this district. This is actually because the experimental sites had high soil P content (Table 2). In Mojana Wodera district the highest yield observed from K omitted treatment was found statically similar with other treatments except the control (Table 5).

Table 5. Effect of nutrient omission on agronomic and yield related parameters of wheat

	Plant height		Spike length		Fertile tiller		Harvest Index	
Nutrient	MJ	MW	MJ	MW	MJ	MW	MJ	MW
Control	54.6^{d*}	62.9^{d}	5.57^{d}	5.09^{c}	2.66^{c}	2.57^{b}	0.4^{b}	0.2^{e}
All-N	54.8^{d}	63.8^{d}	5.43^{d}	5.13^{c}	2.48^{c}	2.73^{b}	0.44^{a}	0.24^{e}
All-P	85.6^{c}	81.7^{c}	8.2^{bac}	7.13^{b}	3.11^{b}	3.65^{a}	0.45^{a}	0.5^{bdc}
All-K	87.1^{bac}	88.4^{a}	8.5^{bac}	7.51^{a}	3.51^{a}	3.87^{a}	0.44^{a}	0.56^{bac}
All-S1	86.3^{bc}	85.2^{b}	8.21^{bac}	7.17^{b}	3.25^{ba}	3.83^{a}	0.45^{a}	0.46^{d}
All-Zn	88^{ba}	86^{ba}	8.05^{c}	7^{b}	3.13^{b}	3.6^{a}	0.44^{a}	0.58^{ba}
All-B	87.4^{bac}	85.8^{ba}	8.12^{bc}	7.14^{b}	3.36^{ba}	3.71^{a}	0.44^{a}	0.55^{bdac}
NP	86.3^{bc}	84.1^{bc}	8.13^{bc}	6.96^{b}	3.28^{ba}	3.57^{a}	0.45^{a}	0.48^{dc}
NP+S2	89.1^{a}	86.6^{ba}	8.64^{a}	7.15^{b}	3.36^{ba}	3.88^{a}	0.44^{a}	0.55^{bdac}
All	87.6^{bac}	86^{ba}	8.54^{ba}	7.1^{b}	3.32^{ba}	3.64^{a}	0.45^{a}	0.59^{a}
LSD (0.05)	2.4	2.92	0.48	0.34	0.31	0.34	0.0257	0.094
CV(%	5.21	4.99	11	6.9	17.18	13.4	10.3	27.5

[*a, b, c] Mean value with different letters of superscript with in the column are significantly different ($P<0.05$), MJ= Moretina Jiru, MW= Mojana Wodera,

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). In Moretina Jiru district the highest (26 Kgha^{-1}) and lowest (-36 KgKg^{-1}) agronomic efficiency were recorded with application of S and B nutrient respectively. Application of N, P, Zn and K nutrient also resulted in agronomic efficiency of 22 KgKg^{-1}, 5 KgKg^{-1}, and 2 KgKg^{-1}, and 1 KgKg^{-1}, respectively. Application of K fertilizer resulted in agronomic efficiency of 0 KgKg^{-1} in this district (Figure 2). Indicating that the application of this nutrient does not increase wheat yield and the indigenous soil supply of this nutrient is the highest and external application of this nutrient is not required (Congreves *et al*., 2021). In Mojana Wodera district, the highest (71 KgKg^{-1}) agronomic efficiency was recorded with application of Zn and B nutrients. The lowest agronomic efficiency (0Kgha^{-1}) was recorded from application of K nutrient. In between, application of P, N, and S nutrient resulted in agronomic efficiency of 28 KgKg^{-1}, 137KgKg^{-1}, and 13 KgKg^{-1}, respectively (Figure 2)

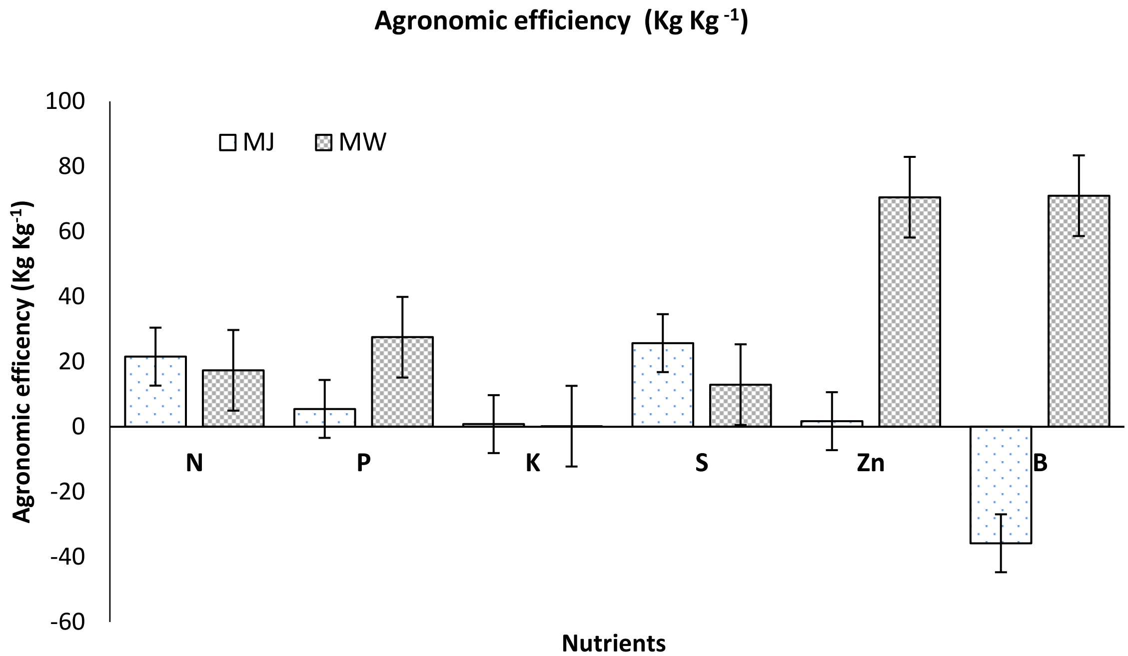

Figure 2. Agronomic efficiency of wheat for application of different nutrient in Moretina Jiru district (MJ) and Mojana Wodera district (MJ)

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 all the measured parameters were responded for nutrient omission treatment in both locations. Higher mean grain yield of 5073 Kgha^{-1} and biomass yield of 11474 Kgha^{-1} wheat were recorded with application of 30 Kgha^{-1} with recommended NP rate in Moretina Jiru district. In this district the lower grain and biomass yield were observed from the control (without nutrient application) and N omitted treatments indicating that N was the most yield limiting nutrient for wheat production. In this district, Nitrogen, Sulphur and Phosphorus nutrients were identified as the most yield-limiting nutrients for the study area and soils type and the application of Potassium, Zinc, and Boron nutrients didn’thave a significant wheat grain yield advantage over the applied Nitrogen and Phosphorus nutrients. Therefore, agronomic and economic optimum rates of N, S and P should be done for wheat in this district. In Mojana Wodera district, higher mean grain 4009 Kgha^{-1} and biomass yield of 9949 Kgha^{-1} was recorded from application of all nutrientsy. In this district, Nitrogen, Phosphorus and Sulphur nutrients identified as the most yield-limiting nutrients for the study area and soils type. Therefore, agronomic and economic optimum rates of N, P and S should be studied for wheat in these districts.

References

Abebe Ayele, Girma Abera, and Sheleme Beyene. "Assessment of the limiting nutrients for wheat (*Triticum aestivum* L.) growth using Diagnosis and Recommendation Integrated System (DRIS)." *Communications in Soil Science and Plant Analysis* 49, no. 21 (2018): 2653-2663.

Abdulkadir Birhan, Sofiya Kassa, Temesgen Desalegn, Kassu Tadesse, Mihreteab Haileselassie, Girma Fana, Tolera Abera, Tilahun Amede, and Degefie Tibebe. "Crop response to fertilizer application in Ethiopia: a review." *Tamene L; Amede T; Kihara J; Tibebe D; Schulz S. (Eds.)*.

Abdurahman Husien, Tilahun Abera and Tilahun Firomsa (2021). Determination of NPS fertilizer rates based on Pc and Pf for yield and yield components of bread wheat (Triticum Aestivum L.) in Negelle Arsi District, West Arsi Zone of Oromia, Ethiopia. Journal of Agricultural Science and Practice Volume 6(2), 24-29. https://doi.org/10.31248/JASP2021.258

Abiye Astatke, Mamo Tekalign, P. Don, and D. Mamadou. (2004). Participatory on-farm conservation tillage trial in the Ethiopian highland vertisols: The impact of Potassium application on crop yields. Experimental Agriculture 40(3): 369–79.

Adamu Molla. 2018. Response of wheat to NP fertilizer rates, precursor crops and types of vertisols in central highlands of Ethiopia. Journal of Agricultural Science, 10(4), 231-244

Almaz Admasu. (2021). Response of sulphur fertilizer application to bread wheat (Triticum aestivum) growth and yield in Kulumsa, Arsi, Ethiopia. Asian Journal of Plant Science & Research, 11(7), 1-5.

Asadallah, N. (2014). Wheat production price perfor-mance prediction in the Iranian north province. African Journal of Agricultural Research, 9(1), 74-79. https://doi.org/10.5897/AJAR11.429

Assefa Menna. (2016). Sulphur status of soils and wheat plants in three representative areas of the central highlands of Ethiopia. PhD. Dissertation, University of agriculture. Morogoro, Tanzania.

Assefa Menna. (2022). Response of wheat (Triticum aestivum L.) to Sulphur impurity supplied as triple-super phosphate under gypsum and urea fertilizer bacKgrounds. African Journal of Agricultural Research, 18(5), 353-367. Https//DOI: 10.5897/AJAR2022.15970

Aulakh, M.S. (2003). Crop responses to sulphur nutrition. In: Sulphur in Plants (Editors: Y.P. Abrol and A. Ahmad), pp. 341-358. Kluwer Academic Publishers, Dordrecht, Netherlands

Ayele Abebe, Girma Abera and Sheleme Beyene. (2020). Sorption characteristics, growth and yield response of wheat (*Triticum aestivum* L.) to application of essential nutrients on Nitisol and Vertisol of Central Highland of Ethiopia. African Journal of plant science, 14(3), 108-120. https://doi.org/10.5897/A AJPS2019.1873

Beza Shewangizaw, Kenzemed Kassie, Shawl Assefa, and Tesfaye Feyisa. 2020. Onfarm verification of soil test-based Phosphorus fertilizer recommendations for bread wheat (Triticum aestivum L.) on the vertisols of central highlands of Ethiopia. *Cogent Food & Agriculture* 6(1).

Bizuwork Tafes Desta and Yibekal Almayehu. (2020). Optimizing blended (NPSB) and N fertilizer rates for the productivity of Durum wheat (Triticumturgidum L. var. durum) in central highlands of Ethiopia. Cogent Food & Agriculture 6, 1–20. doi: 10.1080/ 23311932.2020.1766733

Bouyoucos G. (1962). Hydrometer method improved for making particle size analysis of soils. Agron J., 54:464–5.

Chapman HD. (1965). Cation exchange capacity by ammonium saturation. pp 891–901. In: Black CA, Ensminger LE, Clark FE (eds.) Method of soil analysis. ASA, Madison.

CSA. (2021). Agricultural sample survey report on area and production of major crops (Private peasant holdings, Meher season 2019/2020 (2012 E.C.)). The FDRE statistical bulletin, Volume I.

Falola, A., Achem, B. A., Oloyede, W. O., and Olawuyi, G. O. (2017). Determinants of commercial production of wheat in Nigeria: A case study of Bakura local gov-ernment area, Zamfara state. Trakia Journal of Sciences, 15(4), 397–404. https://doi.org/10.15547/ tjs.2017.04.024.

FAO (Food and Agriculture Organization). (2006). Plant nutrition for food security: A guide for integrated nutrient management. Rome Italy.

FAO. FAOSTAT. Available from: http://faostat.fao.org. Accessed 2022 May 15.

Fernando Salvagiotti, Julio M. Castellarín, Daniel J. Miralles, Hugo M. Pedrol. (2009). Sulphur fertilization improves Nitrogen use efficiency in wheat by increasing Nitrogen uptake, Field Crops Research, 113(2), 170–177. https://doi.org/10.1016/j.fcr.2009.05.003.

Fresew Belete, Nigussie Dechassa, Adamu Molla and Tamado Tana. (2018). Effect of Nitrogen fertilizer rates on grain yield and Nitrogen uptake and use efficiency of bread wheat (Triticum aestivum L.) varieties on the Vertisols of central highlands of Ethiopia. Agriculture & Food Security, 7(78). https://doi.org/10.1186/s40066-018-0231-z

Gebrehawariyat, F. M., W. Haile, T. Mamo, I. Zipori, and E. Sokolowski. (2018). Response of Tef [Eragrostis tef (Zucc.) Trotter] to Potassium Fertilizer Application in Four Districts of North Shewa, Ethiopia, e-ifc No. 53.

Getachew Agegnehu, Paul N. Nelson, Michael I. Bird & Christy van Beek (2015) Phosphorus Response and Fertilizer Recommendations for Wheat Grown on Nitisols in the Central Ethiopian Highlands, Communications in Soil Science and Plant Analysis, 46:19, 2411-2424. https://doi.org/10.1080/00103624.2015.1081922

Congreves, K. A., Otchere, O., Ferland, D., Farzadfar, S., Williams, S., & Arcand, M. M. (2021). Nitrogen use efficiency definitions of today and tomorrow. *Frontiers in Plant Science*, *12*, 637108.

Hillette Hailu, Tekalign Mamo and R. Keskinen. (2017). Response of Wheat (Triticum aestivum L.) to Phosphorus and Potassium Fertilization on Vertisols in Ethiopia's Central Highlands, e-ifc No. 49.

Hiwot, Lemlem. (2012). Evaluating the effect of low seeding rate, planting method and blended fertilizer application on Eragrostis tef (Kuncho variety) yield, yield component and nutrient uptake by grain grown on Regosols and Vertisols [MSc Thesis]. Mekelle University.

Horneck, D.A. Sullivan D.M, Owen, J.S. and Hart J.M. (2011). Soil test interpretation guideline. Oregon State University, Extension Service.

Ishete Tilahun Abera and Tana Tamado. (2019). Growth, yield component and yield response of durum wheat (Triticum turgidum L. var. Durum) to blend NPS fertilizer supplemented with N rates at Arsi Negelle, Central Ethiopia. African Journal of Plant Science 13, 9–20. Doi: 10.5897/AJPS2018.1697

Jones BJJ. (2001). Laboratory guides for conducting soil tests and plant analysis. London: CRC Press.

Jones, J.B. (2003). Agronomic Handbook: Management of Crops, Soils, and their Fertility: CRC, Boca Raton. 450

Kiros Habtegebrial, Singh BR. (2009). Response of wheat cultivars to N and S for crop yield, Nitrogen use efficiency and protein quality in the semiarid region. J Plant Nutri. 32:1768–87.

Kiss, I. (2011). Significance of wheat production in world economy and position of Hungary in it. Abstract: Applied studies in agribusiness and commerce [Thesis]. University of Debrecen.

Kumar, B., Sharma, G. K., Mishra, V. N., Pradhan, A., & Chandrakar, T. (2018). Assessment of nutrient deficiencies based on response of rice (Oryza sativa L.) to nutrient omission in inceptisols of Kondagaon district of Chhattisgarh in India. *International Journal of Current Microbiology and Applied Sciences*, *7*(9), 350-359.

Kumar, A., Majumdar, K., Jat, M. L., Pampolino, M., Kamboj, B. R., Bishnoi, D. K., & Johnston, A. M. (2012). Evaluation of nutrient Expert TM for wheat. *Better Crops-South Asia*, *6*, 27-29.

Landon, J. (1991). Booker tropical soil manual: A hand book for soil survey and agricultural land evaluation in the tropics and subtropics. New York: John Wiley and Sons.

Landon, J., Manual, B.T.S., 1991. A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical Group Ltd, Hong Kong

Liben Feyera, Midega Tesfaye, Tufa Tolcha, Wortmann CS. (2020). Barley and wheat nutrient responses for Shewa, Ethiopia. *Agronomy Journal*. 2020; 112:1309–1317. https://doi.org/10.1002/agj2.20020

Limin Chuan, Ping He, Jiyun Jin, Shutian Li, Cynthia Grant, Xinpeng Xu, Shaojun Qiu, Shicheng Zhao, Wei Zhou. (2013). Estimating nutrient uptake requirements for wheat in China. Field Crops Research, 146. 96-104. https://doi.org/10.1016/j.fcr.2013.02.015.

Melesse Harfe. 2017. Response of bread wheat (Triticum aestivum L.) varieties to N and P fertilizer rates in Ofla district, Southern Tigray, Ethiopia. African Journal of Agricultural Research, 12(19), 1646-1660. https://doi.org/10.5897/AJAR2015.10545

MoANR and ATA (2016) Soil fertility status and fertilizer recommendation Atlas of Amhara National Regional State. Ethiopian Soil Information System (EthioSIS). In Shiferaw HTH, Mamo T (Ed.), (Vol. 1). Addis Ababa, Ethiopia

Olsen SR, Cole CV, Watanabe FS, Dean LA. (1954). Estimation of available Phosphorus in soils by extraction with sodium carbonate. USDA Circular. 939:1–19

Saeed, B., Gul, H., Zaman, K. A., & Parveen, L. (2012). Growth factors and straw yield of wheat cultivars in relation with Nitrogen and Sulphur fertilization. Asian Research Publishing Network (ARPN). Journal of Agricultural and Biological Science, 7 (1), 1103–1109

SAS Institute Inc. (2012). SASR 9.3 Macro Language: Reference. Cary, NC: SAS Institute Inc. Stoorvogel, J. J., Smaling, E. M. A. 1993. Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983–2000. TechnicalReport Winand Staring Centrum, Wageningen.

Shawl Assefa, Wassie Haile, Wondwosen Tena. (2021). Effects of Phosphorus and Sulphur on yield and nutrient uptake of wheat (Triticum aestivum L.) on Vertisols, North Central, Ethiopia. Heliyon, 7, 1-12. https://doi.org/10.1016/j.heliyon.2021.e06614

Sofonyas Dargie, Tsegaye Girma, Tilahun Chibsa, Sofia Kassa, Shiferaw Boke, Abate Abera, Berekethaileselassie, Samuel Addisie, Sosina Amsalu, Mehretab Haileselassie, Shure Soboka, Wuletawu Abera and Sileshi G. Weldesemayat. (2022). Balanced fertilization increases wheat yield response on different soils and agroecological zones in Ethiopia. Experimental Agriculture, 5, 1–13 https://doi.org/10.1017/S0014479722000151

Tadesse Wuletaw, Bishaw Zewdie, Assefa Solomon. (2019). Wheat production and breeding in Sub Saharan Africa: Challenges and opportunities in the face of climate change. Int J Clim Chang Strateg Manag. 11(5):696-715.

Tadele Amare, Zerfu Bazie, Erkihun Alemu1, Asmare Wubet, Birhanu Agumas, Mengistu Muche, Tesfaye Feyisa and Desalew FentieAmare T, Bazie Z, Alemu E, Wubet A, Agumas B, Muche M, Fentie D. (2018). Crop responses to balanced nutrients in northwestern Ethiopia. Blue Nile J Agric Res 1(1):1–14

Tekalign, Tadesse. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant division working document 13. Addis Ababa, Ethiopia: ILCA.