5. Yield-Limiting Plant Nutrients on Wheat Productivity under Irrigation in North Shoa Zone, Ethiopia

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Abstract

The consecutive two years over six locations field experiment was conducted during irrigation seasons of 2021 and 2022 on clay and clay loam soils to assess the yield limiting nutrients on growth, yield and yield components of wheat. The experiment consisted of 9 treatments, including application PKSZnB (N-omitted), NKSZnB (P-omitted), NPSZnB (K-omitted), NPKZnB (S-omitted), NPKSB (Zn-omitted), NPKSZn (B-omitted), NPKSZnB, recommended NP, and control (without nutrient input). Treatments were randomized and arranged in a randomized complete block design and replicated tree times at a site. The soil analysis result of the experimental locations indicated neutral to moderately alkaline soil reaction, low to moderate organic matter and total Nitrogen, medium to high available P, high to very high exchangeable K and low to medium ranges of available S. The grain and biomass yield result of the experiment revealed that Nitrogen is the most yield limiting nutrient and there was a reduction in wheat grain yield 29.13% 7.36% and 1.04% for the omission of N, S and P respectively. *Nutrients K, B and Zn omission resulted in no significant positive impact on yield, even there were cases that application of these nutrients showed yield penalty. There was high nutrient response variability across locations. All sites responded to N. While 67.0% of the study sites showed response to S application. Therefore, it can be concluded that not only N and but also, S important in the study site for the production of wheat under irrigation system.*

Keywords: Nutrients omission, Yield limiting nutrients, Wheat under irrigation, North-shoa

Introduction

Excessive degradation of soil fertility is the major consequence of low crop productivity (Paavola, 2008; Tena and Beyene, 2011; Shepherd *et al.*,2015). The lower productivity of crops in Ethiopia is mostly related to intensive cropping, imbalanced fertilization, inadequate application of organic manures, and soil erosion (Birhan *et al.,* 2016). Matching between applied nutrients, soil supplies and plant needs considerably improves the efficiencies of applied inputs, and productivity and profitability of crops (Akram *et al.,* 2022).

Wheat (*Triticum aestivum* L.) is an important crop which providing that supports about 35% of world population (Akram *et al.,* 2022)., Its global area coverage is about 220 million ha with a total of 750 million t production per year (Tadesse *et al.,* 2018). Its important is continuously increased over the years in Ethiopia and one of the most strategically important cereal crops prioritized by the government. The target of the government of Ethiopia is to increase the production of wheat both by increasing the productivity and increasing the area (including by irrigation). This target can be achieved by using efficient management of fertilizers, using improved seeds, management of pests, etc. Ethiopia is one of the major wheat producing countries in sub-Saharan African countries followed by South Africa, Sudan and Kenya (Tadesse *et al.*, 2018). The current productivity of wheat in the country is 3.88tha^{-1} (CSA, 2021) which is still lower compared to its attainable potential of greater than 5-tha-1 (Birhan *et al.,* 2016).

Nutrient management involves using crop nutrients as efficiently as possible to improve productivity while protecting the environment. When applied in proper quantities and at the right times, added nutrients help to achieve optimum crop yields; applying too little limit yield while applying too much does not make economic sense it rather can harm the environment (Khokhar, 2019).

For fertilizer use to be efficient and environment-friendly, balanced use is a prerequisite. Therefore, adequate mineral fertilization is considered to be one of the most important requirements for better yield and quality of crops (Parashar *et al.,* 2020). One nutrient could be more yield-limiting than the other in different soils and environmental conditions. Nutrient inadequacies can affect the crop's ability to utilize other nutrients supplied. This leads to the need for investigating yield-limiting factors in various regions of the country. Identification of the most yield-limiting nutrient is the most important in formulating nutrient management strategies to maximize the profitability of crop and forage production while protecting the environment.

In targeting the right fertilizers to the right places, the EthioSIS (2014) revealed that in addition to N and P, identified a number of essential plant nutrients that are deficient and critically required by the agricultural soils of the country. Accordingly, the country customized the use of a number of soil nutrients and that were identified deficient in the agricultural soils appeared on the fertilizer market before the validation studies.

Thus, the evaluation/validation of the soil fertility map developed by EthioSis can help to determine which nutrients are the most limiting to crop production and hence the nutrient omission technique the simplest and straight forward technique evaluates the nutritional requirements of crops and the most yield limiting nutrient (Laviola & Dias 2008; Miranda *et al.*, 2010). Therefore, this research was initiated to identify nutrient(s) that are major yield-limiting in Kewot and Efrata Gidim districts under irrigation for bread wheat production.

Materials and Methods

Description of the Study Areas: The experiment was conducted for two consecutive (2020-2021) irrigation seasons on six locations at Kewot (Chare, Wanza, Merye) and Efrata Gidim (Freedwoman, Yimilo1, and Yimilo2) districts. *Annual mean minimum and maximum temperatures were 10 and 25^{o}c, respectively.* The study locations have a uni-modal rainfall pattern and receiving an average annual rainfall range from 900-2000 mm at Kewot and 900-1200 mm at Efra tana Gidim. Vertisols are the dominant soil in the study area. Major crops grown under irrigation are onion, cabbage, tobacco and pepper, in decreasing orders of area coverage. Fig 1 represents the location map of the study areas.

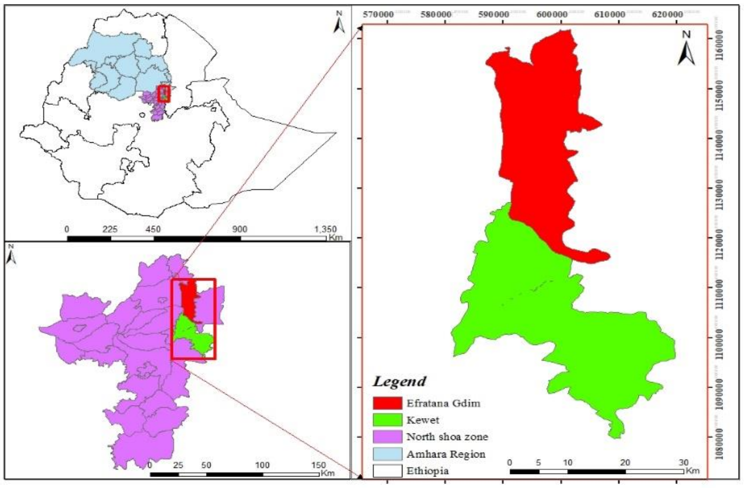

Figure 1. Location map of the study area

Treatments and Experimental Design: In an omission plot, adequate amounts of all nutrients are applied except for the omitted nutrient. The yield in such an omission plot is related to the soil supplying capacity of the omitted nutrient. The nutrient omission trials (NOTs) consisted of nine treatments i.e., PKSZnB (N-omitted), NKSZnB (P-omitted), NPSZnB (K-omitted), NPKZnB (S-omitted), NPKSB (Zn-omitted), NPKSZn (B-omitted), NPKSZnB, recommended NP, and control (with no nutrient input). The amount of each nutrient in the treatment (Kgha^{-1}) were N= 111, P_2O_5= 38, K_2O = 60, S= 10.5, Zn = 5, and B= 1. The experiment was laid out in randomized complete block design (RCBD) and replicated three times across each farmers' field.

Table1. Treatment details

No	Treatments	Treatment Details
1	- N (PKSZnB)	The N-limited yield is measured in a zero-N omission plot. The plot receives sufficient fertilizer P, K, S, Zn, and B to achieve high yield, but no fertilizer sources of N are applied.
2	-P (NKSZnB)	The P-limited yield is measured in a zero-P omission plot. The plot receives sufficient fertilizer N, K, S, Zn, and B to achieve high yield, but no fertilizer sources of P are applied.
3	-K (NPSZnB)	The K-limited yield is measured in a zero-K omission plot. The plot receives sufficient fertilizer N, P, S, Zn, and B to achieve high yield, but no fertilizer sources of K are applied.
4	-S (NPKZnB)	The S-limited yield is measured in a zero-S omission plot. The plot receives sufficient fertilizer N, P, K, Zn, and B to achieve high yield, but no fertilizer sources of S are applied.
5	-Zn (NPKSB)	The Zn-limited yield is measured in a zero-Zn omission plot. The plot receives sufficient fertilizer N, P, K, S, and B to achieve high yield, but no fertilizer sources of Zn are applied.
6	-B (NPKSZn)	The B-limited yield is measured in a zero-B omission plot. The plot receives sufficient fertilizer N, P, K, S, and Zn to achieve a high yield, but no fertilizer sources of B are applied.
7	NPKSZnB	Full fertilization of nutrients applied, Fertilizers N, P, K, S, Zn, and B are applied sufficiently to ensure that yield is not limited by an insufficient supply of the added nutrients. Grain yield in the plot with full fertilization and crop management can be used to estimate an attainable yield target
8	RNP	Only recommended amount of N and P is applied. The yield without N, P limitation is measured in a plot receiving the same N rate used in the –N plot, the same P rate used in the –P plot
9	Control	The Nutrient-limited yield is measured in a no fertilizer that should not receive any fertilizer of N, P, K, S, Zn, and B.

Table 2. Each nutrient application rates (Kgha^{-1})

No	Treatment	Nutrient (Kgha^{-1})					
		N	$P_2 0_5$	$K_2 0$	S	Zn	B
1	- N (PKSZnB)	0	38	60	10.5	5	1
2	-P (NKSZnB)	111	0	60	10.5	5	1
3	-K (NPSZnB)	111	38	0	10.5	5	1
4	-S (NPKZnB)	111	38	60	0	5	1
5	-Zn (NPKSB)	111	38	60	10.5	0	1
6	-B (NPKSZn)	111	38	60	10.5	5	0
7	NPKSZnB	111	38	60	10.5	5	1
8	RNP	111	38	0	0	0	0
9	Control	0	0	0	0	0	0

Management of the Experimental Field: The NOTs study sites were randomly selected at 6 farmer lands each year. The experimental fields for all NOTs were prepared with an oxen-drawn moldboard plow before planting and human power at planting time. The plot sizes of each treatment was 7.2 m^2, and wheat variety Kekeba was used. Plant spacing of 20 cm between-rows was used and the space between plots and replications was 2m and 2.5m respectively. All nutrients were applied at planting while N was applied in two equal splits: half at planting, and the resthalf after 35 days of planting. Urea, triple superphosphate (TSP), Muriate of potash (MOP), Zinc EDTA, $MgS0_4$, and borax were used as fertilizer sources for N, P, K, Zn, S, and B, respectively. Weeds, diseases, and pests managements were uniform for all plots.

Data Collection: Parameters like growth and yield components (plant height, spike length, number of totals, and fertile tilers) and grain, and straw yield for each site were collected following the procedures stated below

Plant Height (cm): An average height of ten plants, in each experimental plot was measured from ground to the tip of the spike excluding awns.

Number of Total Tillers: number of total tillers was counted in each plot at different location of plot and values averaged for a single reading.

Number of Fertile Tillers Plant^{-1}: number of fertile tillers per plant was counted in each plot at different location of plot and values averaged for a single reading.

Spikes Length was measured from10 randomly selected spikes atharvest from each plot through measuring tape and average to represent the spike length in centimeters (cm).

Grain Yield (Kgha^{-1}): grain yield in Kg/plot and the moisture content was simultaneously measured for each treatment and finally adjusted to 12.5% moisture content.

Straw Yield (Kgha^{-1}): It was the difference between the total biomass yield and the grain yield.

Soil Sample Collection and Analyses: After selecting the experimental sites, pre-planting soil samples were collected from each site for the analyses of selected physicochemical properties. Composite soil samples were taken from each site from a depth of 0-20 cm using an auger randomly from 10 spots by walking in a zigzag pattern. After thoroughly mixing, 1 Kg of the composite samples was taken and air dried and grounded to pass a 2 mm mesh-sized sieve.

The soil texture was anlysed following Bouyoucous hydrometer method (Bouyoucous, 1962). The pH of the soil was measured using the pH-water method by making a soil-to-water suspension of a 1: 2.5 ratio and was measured using a pH meter. The soil OC content was determined by the wet digestion method (Walkley and Black, 1934). Total Nitrogen (TN) was determined by using the modified micro Kjeldahl method (Coterie, 1980), and available P (ava. P) was analyzed using Olsen's calorimetric method as described by Olsen *et al.,* (1954).

Statistical Analysis: The collected data were subjected for the analysis of variance (ANOVA) using R software program using R version 4.2.1 (R Core Team, 2022). Normality and homogeneity of variance tests were checked and combined analysis for the 6 sites and the 2 years was done. The Least Significant Difference (LSD) at 5% level was used to separate the treatment means for those parameters that were statistically significant.

Results and Discussion

Soil Physicochemical Properties: The initial physicochemical characteristics of the experimental soil were determined using standard laboratory procedures as mentioned earlier. The soils of the experimental locations were belonging to clay to clay loam textural class. The soil pH of the study sites ranges from 6.7 to 8.16. The average the soil pH of the six sites is 7.52 with slightly alkaline soil reaction (Murphy, 1968), it is near to the ideal soil pH value of crop needs, therefore it needs closely monitored. Based on the analysis result the TC ranged low to moderate and he average was found in low TC soil chemical categories (Berhanu, 1980). TN was ranged from 0.067% to 0.165% with average value of 0.12 which was under low categories according to soil chemical characteristics (Tekalign,1991). The test crop was also significantly responded to the application N in the testing location. The available of soil P for the study sites ranged from 9.75 $mgKg^{-1}$ to 18.92 $mgKg^{-1}$. Based on the result the average available soil P content was under high range (Olsen *et al.*, 1954), the available P of the study sites was above the critical P content which is sufficient for crop production. Sufficient soil P is important for achieving optimal crop production, but excessive soil P levels may create a risk of P losses and eutrophication of surface waters. The test crop was not significantly responded to the application of P. There could be maintenance Phosphorus application is important. The soil analysis result showed low to medium ranges of available S (Hariram and Dwivedi, 1994). Based on this the soil analysis result indicated the average value of available soil S content is TmN(p)pa8 whict waS but e -99(low)-97, the7-149(c)ritica

Table 4. Effects of nutrient omission on plant height and spike length at each location

Treatment	Plant Height (cm)						Spike Length (cm)					
	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy
-N (PKSZnB)	60.6c	71.20c	93.60	86.27	87.33	88.07	6.73b	7.26bc	8.52	8.83	8.00	8.80
-P (NKSZnB)	69.8bc	81.63ab	96.20	90.03	90.97	89.10	7.75a	8.55a	9.40	8.93	8.23	9.57
-S (NPKZnB)	73.67b	80.37ab	96.77	89.69	89.43	87.47	7.94a	8.92a	9.58	8.68	8.15	9.22
-K (NPSZnB)	72.23b	84.77a	95.17	90.55	89.97	87.00	7.85a	8.81a	9.04	8.53	8.13	9.18
-Zn (NPKSB)	77.67ab	84.93a	95.57	87.03	91.60	88.33	8.00a	8.46a	9.22	8.40	8.40	9.13
-B (NPKSZn)	71.13b	79.73ab	95.20	88.80	90.73	87.53	7.72a	8.64a	9.71	8.90	8.55	9.15
NPKSZnB	76.53ab	86.17a	95.37	88.03	90.87	88.43	7.75a	8.68a	9.47	9.13	8.37	8.87
RNP	76.83ab	82.00a	95.00	89.80	91.53	88.43	7.67a	8.60a	8.87	8.77	8.62	9.60
Control	59.47c	74.43bc	93.00	87.27	84.23	88.63	6.77b	6.93c	8.65	8.30	7.90	8.78
LSD (<0.05)	10.51	6.51	ns	ns	ns	ns	0.65	0.55	ns	ns	ns	ns
CV (%)	8.47	4.71	2.82	2.92	3.18	2.22	4.99	3.87	5.51	4.96	7.15	2.80

Effects of Nutrients Omission on Yield and Harvest Index: The analysis of variance showed that grain and straw yield responded significantly to nutrient omission treatments (Table 5 and 6). The mean combined data of grain and straw yield of wheat significantly influenced by nutrients omission. All sites responded to Nitrogen omissions strongly while, 67.0% to Sulphur. Omission of P, K, S, Zn and B had no statistical difference.

Table 5. Effect of nutrient omissions on the grain yield ($Kgha^{-1}$)

Treatment	Sites					
	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy
-N (PKSZnB)						

comparison to treatment where all the nutrients were supplied except the control. The largest reduction in the grain yield was observed with the omission of Nitrogen followed by Sulphur and Phosphorus. The study showed that the grain and straw yield reduction was more noticeable with N omission. The yield reduction was also observed from S omission. The addition of K, Zn, and B caused grain yield penalty numerically compared to omission of those nutrients (Table).

The summarized data from Table and Figure showed that the reduction of grain yield due to omission of different nutrients from treatment that received all nutrients and relative importance of each nutrient in comparing with treatment that received all nutrients. Compared to the results of N omissions, the highest grain yield reduction (29.13%) followed by S (7.36%) and P (1.04%). Large reductions in the grain yield were observed with the omission of N and S compared to other nutrients. This implies that N is the most critical nutrient that affect grain yield considerably followed by S. Lower yield for N and S omission indicated that the N and S application cannot be supplied from the soil. This means the inherent N and S supplying capacity of the soil is not sufficient to for optimum production of wheat. It was in line with the soil analysis report from the study locations revealed that there was low total N content and low to medium available S (Table). Therefore, the present research finding revealed that N is the most yield limiting plant nutrient. Sulphur is becoming deficient and became a yield limiting nutrient in some sites of the study areas. The finding of this research is in line with the findings of Wondwosen and Sheleme, (2011), Ahmed *et al.,* (2014), Qureshi, (2016), and Ekka *et al.,*, (2020), stated that N is the most plant yield limiting nutrients and S is becoming deficient and identified as a yield-limiting nutrient. Assefa (2016) and Assefa (2022) studied the response of wheat to S on *vertisols* and *Nitisols* and his result indicated that that wheat significantly responded to S application. Soils that responded to S were having S below critical level S. In contrast to this study, reported by Abebe *et al.,* (2021), there was no a significance yield differences observed with application of all nutrients in the form of blended fertilizer compared to recommended NP.

Table 6. Effects of nutrients omission on straw yield of wheat (Kgha^{-1})

Treatment	Sites					
	Yimilo1	Yimilo2	Feredewuha	Merye	Wanza	Aregawy
-N (PKSZnB)	1457.87^{b}	2942.13^{c}	7766.20^{b}	7791.67^{bc}	5851.85^{c}	8990.67^{ab}
-P (NKSZnB)	3923.61^{a}	4842.59^{ab}	8971.76^{a}	9085.33^{abc}	7863.42^{ab}	10884.00^{ab}
-K (NPSZnB)	4073.61^{a}	5290.51^{a}	8617.59^{ab}	9745.67^{a}	7590.28^{b}	10956.00^{a}
-S (NPKZnB)	3854.63^{a}	6081.02^{a}	8261.10^{ab}	7772.33^{bc}	7389.58^{b}	9166.67^{ab}
-Zn (NPKSB)	4189.82^{a}	5526.85^{a}	8245.37^{ab}	9259.33^{ab}	8016.20^{ab}	10662.00^{ab}
-B (NPKSZn)	3852.78^{a}	5741.90^{a}	8580.09^{ab}	8597.33^{abc}	7821.76^{ab}	10217.00^{ab}
NPKSZnB	3957.41^{a}	5221.30^{a}	8896.76^{a}	9229.33^{ab}	7810.18^{ab}	9851.33^{ab}
RNP	3909.26^{a}	5541.67^{a}	9265.28^{a}	8206.00^{abc}	7097.22^{b}	9651.00^{ab}
Control	1552.41^{b}	3435.19^{bc}	5289.35^{c}	7356.67^{c}	5583.33^{c}	8531.67^{b}
LSD (<0.05)	1863.22	1163.13	1379.45	1029.39	1442.18	1127.12
CV (%)	7.36	9.18	8.06	17.39	16.80	7.93

Table 7. The effects of nutrient omission on mean grain yield, straw yield and harvest index over locations and years

Treatment	Grain Yield (Kgha^{-1})	Straw Yield (Kgha^{-1})	Harvest Index (%)
-N (PKSZnB)*	3497.70c	5800.10d	38.35
-P (NKSZnB)	4884.20a	7595.20ab	40.22
-K (NPSZnB)	5022.00a	7712.20a	40.33
-S (NPKZnB)	4572.10b	7087.50c	39.61
-Zn (NPKSB)	5032.50a	7649.90ab	40.37
-B (NPKSZn)	5085.30a	7468.40abc	41.17
NPKSZnB	4935.40a	7494.40abc	40.41
RNP	4776.50a	7278.40bc	40.85
Control	3439.20c	5291.40e	40.48
LSD (P<0.05)	201.21	458.39	ns
CV (%)	8.85	9.74	13.8

**NPKSZnB=All, RNP=recommended N and P, All-N=PKSZnB (N omitted), All-P= NKSZnB (P omitted), All-K = NPSZnB (K omitted), All-S= NPKZnB (S omitted), All-B= NPSKZn (B omitted), All-Zn= NPSKB (ZN omitted), control=no fertilizer (no nutrient) applied.*

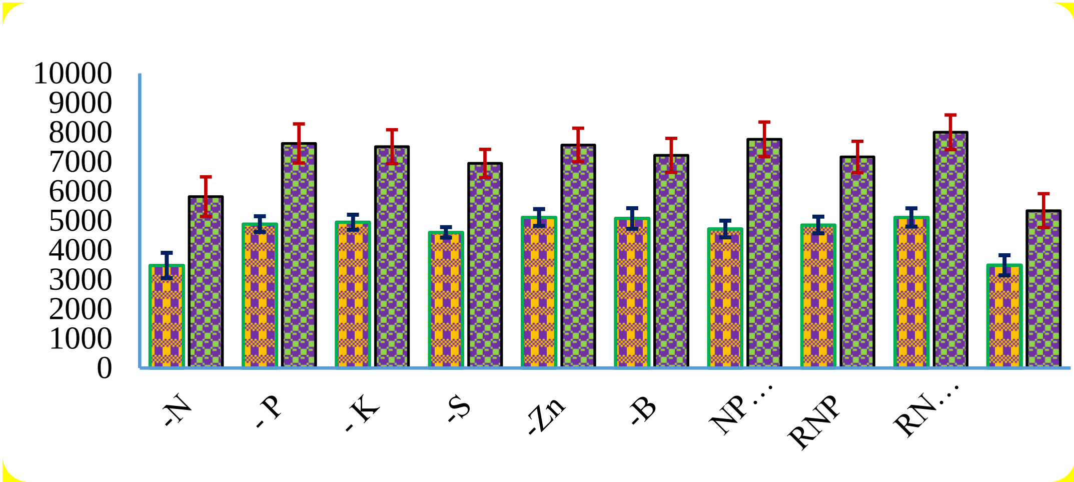

Figure 2. Effects of nutrient omission on grain and Straw Yield of Wheat under irrigation

Table 8. Grain yield reduction for each nutrient omission compared to all the nutrients added

Treatment	Grain Yield ($Kgha^{-1}$)	Grain yield reduction ($Kgha^{-1}$)	% Reduction
-N (PKSZnB)	3597.70	-1437.73	-29.13
-P (NKSZnB)	4884.20	-51.20	-1.04
-K (NPSZnB)	5022.00	86.60	1.75
-S (NPKZnB)	4572.10	-363.30	-7.36
-Zn (NPKSB)	5032.50	97.100	1.97
-B (NPKSZn)	5085.30	149.90	3.04
NPKSZnB	4935.40		
RNP	4776.52		
Control	3539.22		

Table 9. Straw yield reduction for each nutrient omitted compared to all the nutrients added

Treatment	Straw yield ($Kgha^{-1}$)	Straw yield reduction ($Kgha^{-1}$)	% Reduction
-N (PKSZnB)	5800.11	-1694.3	-22.61
-P (NKSZnB)	7595.21	100.80	1.35
-K (NPSZnB)	7712.20	217.81	2.91
-S (NPKZnB)	7087.52	-406.92	-5.43
-Zn (NPKSB)	7649.90	155.50	2.07
-B (NPKSZn)	7468.41	-26.00	-0.35
NPKSZnB	7494.42	-2203.01	-29.40
RNP	7278.40		
Control	5291.43	-	-

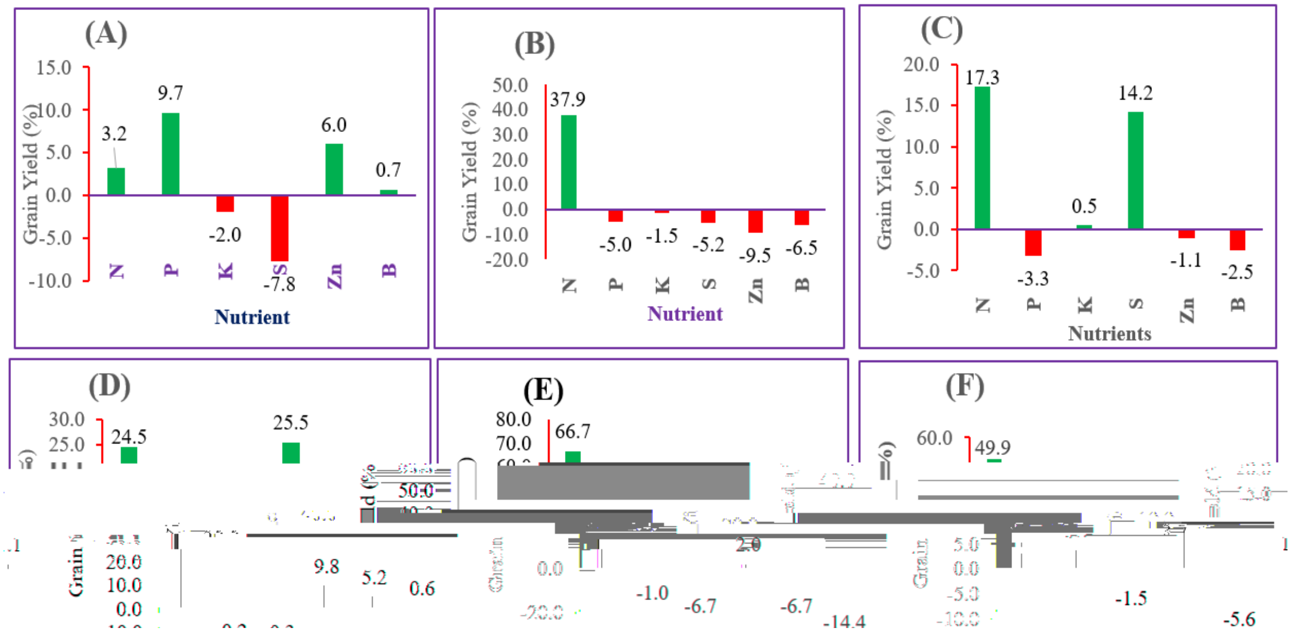

Figure 3. Relative importance of nutrients at (A) Aregawy, (B) Feredewuha, (C) Merye, (D) Wanza, (E) Yimilo-1, and (F) Yimilo-2 on grain yield of wheat

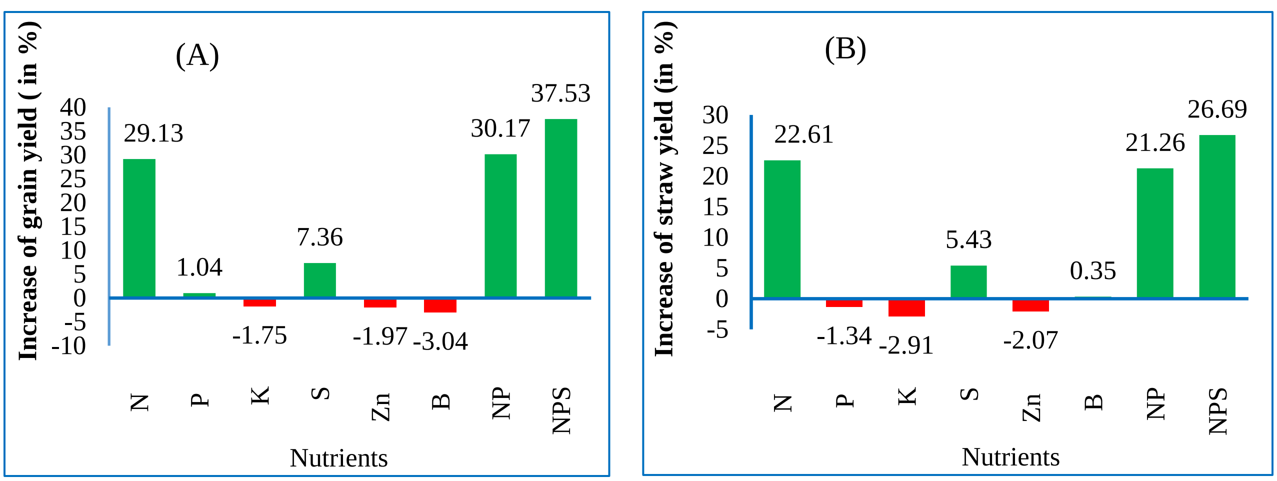

Figure 4. Mean relative importance of nutrients on the grain (A) and straw (B) yields

Conclusion and Recommendation

This study revealed that considerable soil nutrient variabilities exist within the study sites. The soil analysis result of the study sites showed that total N and S was in low to medium ranges. The highest grain yield (5085.30 Kgha^{-1}) was attained with B omitted followed by, Zn and K omitted (5035.5 and 5022.00 Kgha^{-1}) respectively. The lowest grain yield (3497.70 Kgha^{-1}) was obtained without any fertilizer input followed by N omitted (3539.20 Kgha^{-1}). There was no significance difference between RNP and application of all nutrients on grain yield. While, significantly lower grain yield was obtained from treatment received S omitted compared to RNP and All nutrients added. N, S, and P omission resulted in a grain yield penalty by 29.13, 7.36, and 1.04 % respectively. To attain the maximum wheat yield production under irrigation N is the most yield limiting nutrient. K, B, Zn nutrients did not show a positive yield increment. Therefore, only N, P and S were the yield limiting nutrients for the production of wheat under irrigation for the study sites.

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References

Abebe, Getu,., Samuel, Adissie, Tadesse, Hailu, Seid, Belay, Habtemariam, Teshome, & Abreham, Teshager. (2021). *Evaluation of blended fertilizers and validation of soil fertility map-based fertilizer recommendations in Jamma and Werreillu Districts of South Wollo Zone, Amhara Region*. 9–21.

Assefa Menna Sako. (2016). Sulphur status of soils and wheat plants in three representatives *areas* of the central highlands of Ethiopia (Doctoral dissertation, Sokoine University of Agriculture).

Assefa, Mennaa Sako. (2022). Response of wheat (Triticumostium L.) to Sulphur impurity supplied as triple-super phosphate under gypsum and urea fertilizer bacKgrounds. *African Journal of Agricultural Research*, *18*(5), 353-367.

Akram, S. W., Singh, R., Tripathi, P., and Roopa, G. (2022). Effect of Phosphorus and sulphur on yield and economics of wheat (Triticum aestivum L.).

Abdulkadir, Birhan, Sofiya Kassa, Temesgen Desalegn, Kassu Tadesse, and Mihreteab Haileselassie. (2016). "Soil fertility management studies on wheat in Ethiopia: a review." *Ethiopian Journal of Natural Resources* 16, no. 1: 1-23.

Beamlaku, Alemayehu, Adgo, Enyew and Tadele Amare. (2023). Nutrients Limiting Tef [Eragrostis tef (Zucc.) Trotter] Crop Yield on Vertisols in Yilmana Densa, Upper Blue Nile Basin of Ethiopia. *Journal of Plant Growth Regulation*, *42*(5), 2736–2748.

Berhannu Debele. (1982). The physical criteria and their rating proposed for land evaluation in the highland regions of Ethiopia [soil potentiality]. *World Soil Resources Reports (FAO)*.

Bouyoucous, G. J. (1962). Hydrometer method improved for making particle size analyses of soils 1. *Agronomy journal*, *54*(5), 464-465.

Coterie, A. (1980). Soil and plant testing as a basis of fertilizer recommendations. FAO soil bulletin 38/2.Food and Agriculture Organization of the United Nations, Rome.

CSA, R. (2021). The federal democratic republic of Ethiopia central statistical agency report on area and production of major. *Statistical Bulletin*.

EthoSIS (Ethiopian Soil Information System). (2014). Soil analysis report Agriculture Transformation Agency.

Hariram & Dwivedi K.N. (1994). Delineation of Sulphur deficient soil groups in the central alluvial tract of Uttar Pradesh. J. Indian Soc. Soil Sci., 42:284- 286.

Khokhar, Khalid Mahmud. (2019). Mineral nutrient management for onion bulb crops–a review. *The Journal of Horticultural Science and Biotechnology* 94, no. 6 703-717.

Laviola, B. G., and Dias, L. A. S. (2008). Toer e cumuli de nutrients me Folha's e fructose de pinhook manse. *Revest Brasileira de Ciancia do Solo*, *32*(5) 1969-1975.

Murphy, H. F. (1963). *Fertility and other data on some Ethiopian soils*. Imperial Ethiopian College of Agriculture and Mechanical Arts.

Miranda, R. S., Sudaria, F. B., Sousa, A. F., and Gomes Filho, E. (2010). Deficiência nutricional em plântulas de feijão-de-corda decorrente da omissão de macro e micronutrientes. *Revest Ciancia Agronomical, 41*(3) 326-333. https://doi.org/10.1590/S1806-66902010000300002

Olsen S., Cole C., Watanabe F.S. and Dean L.A. (1954). Estimation of available Phosphorus in soils by extraction with sodium carbonate. USDA Circular 939: 1-19.

Paavola J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. Environ Sci Policy.; https://doi.org/10.1016/j.envsci.2008.06.002

Parashar, A., Kumar, S., Gupta, S., Dogra P. and Tyagi, B. (2020). Response of malt barley (Hordeum vulgare L.) varieties to Nitrogen and Sulphur application under Argo-climatic zone IIIa (semiarid eastern plain zone) of Rajasthan. Journal of Cereal Research 12(1):55- 60. http://doi.org/10.25174/2582- 2675/2020/85266

R Core Team, (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Shepherd KD, Shepherd G, and Walsh MG. (2015). Land health surveillance and response: A framework for evidence-informed land management. Agricultural Systems