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Investigation of Yield Limiting Nutrients for Wheat Productivity through Nutrient Omission Trials

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Abstract: This study examines the effect of nutrient omission trials (NOTs) on wheat productivity in West shawa zone, Oromia region, with a focus on identifying yield-limiting nutrients. The experiments were conducted out over ten experimental sites. The experiment was laid out by randomized block design using farmers plot as replications per villages to determine the primary yield-limiting nutrients in wheat crop production using nutrient omission strategies and different nutrient sources. Different source of nutrients were used for the studies. Soil samples were tested to determine the initial nutrient levels, and agronomic data on growth, yield, and efficiency measures were obtained. The results show significant differences in wheat growth and production among treatments, indicating the significance of nitrogen and phosphorus in biomass and grain yield increase. The full NPKSZnB treatment consistently produced the highest yields, demonstrating the necessity of balanced nutrient management strategies specific to local agro-ecological conditions.

Keywords: Nutrient omission, Nutrient management, Yield-limiting nutrients, balanced fertilization.

Research Paper

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1. INTRODUCTION

Agriculture remains an important source of income in Ethiopia, yet its productivity faces significant challenges due to nutrient depletion and declining soil fertility (Agegnehu and Amede, 2017; Desta *et al.*, 2022). Particularly in wheat cropping systems, low soil fertility combined with minimum external nutrient inputs severely hinder crop productivity (Tamene *et al*., 2017).

Despite determinations to increase fertilizer accessibility and usage, many farmers struggle to achieve optimal yields, often applying fertilizers at inadequate rates or using inappropriate nutrient sources. This challenge is complicated by factors such as high fertilizer costs, uncertainty regarding economic returns, and limited technical knowledge on fertilizer application approaches (Hopkins *et al*., 2008). Addressing nutrient insufficiency is vital for raise a profitable agricultural sector (Fageria *et al*., 2006).

Recent government initiatives in Ethiopia have aimed to facilitate smallholder farmers' access to fertilizers, resulting in remarkable enhancements in crop productivity. For instance, wheat yields have doubled from 1.2 t/ha to 3.11 t/ha (CSA, 2022). However, despite these improvements, significant yield differences persevere among farms employing similar fertilizer types and rates.

In response to these challenges, nutrient omission trials represent a favorable method to identify and address the specific nutrient deficiencies limiting cereal crop productivity in Ethiopia. Practically omitting individual nutrients and observing crop responses, these trials offer valued awareness into the key nutrient requirements of cereal crops under local agro-ecological conditions (Amede *et al.*, 2020).

In this condition, this study objects to conduct nutrient omission trials for cereal crops in Ethiopia, aiming on cereal crops, which are vital staples in the Ethiopian diet. In many areas, particularly in wheat production, farmers comprehensively depend on fertilizers, yet often apply them at suboptimal rates due to a lack of site-specific nutrient recommendations and limited understanding of nutrient types. While blended fertilizer recommendations by researchers not meet the required scientific validity and they have not reached all farmers, and some remain unconvinced of their effectiveness in achieving targeted yields. Moreover, nutrient omission trials were designed to identify major yield-limiting nutrients, have not been done successfully in the area. Yield gaps in cereal crops are generally high in Ethiopia (Maize=75%; Wheat=60%; Finger

Millet=44%, Sorghum=50%). (GYGA, http://www.yieldgap.org/ethiopia). Moreover, the yield gap in each crop varies with regions. The yield gap in wheat, for instance, varied with regions from as low as 30% (in Oromia) to as high as 90% (SNNP) (Mann and Warner, 2017) due to difference in climate, soil, crop management etc. Yield gaps due to nutrients, especially N, is quite high and accounts for >50% of the maize yield gap in Ethiopia (TAMASA, unpublished data). The levels of yield penalty due to nutrient omission vary with sites (on average >3 t ha^{-1}in Jimma and Bako area and <1.5 in CRV) due to variability in climate, soil nutrient supply capacity and crop management practices as observed for maize (Tesfaye *et al.*, 2018). The magnitude of N, P, K and other micronutrient effects in limiting crop growth and grain yields may also vary with sites due to difference in soil nutrient supply capacity, crop management history etc. Some studies showed that N and K were the most yield limiting nutrient in wheat than P (Rawal *et al*., 2017). Others showed that N and P are the most yield limiting in wheat than K (Chuan *et al*., 2013). On the other hand, Tesfaye *et al*., (2018) reported that N was the most yield limiting followed by P in maize with K and micronutrients have no effect. Thus, appropriate fertilization based on the relative importance of a given nutrient in limiting crop growth and yield, is necessary to contribute to closing the Yield Gaps in different crops.

The yield gap is mainly due to poor crop and fertilizer management practices, such as application of low fertilizer rates, low nutrient use efficiency, unbalanced fertilization and high spatial and temporal variability in crop response to fertilizers. Nutrient omission trials help in determining the most yield limiting nutrients in an area which in turn helps researchers to base their further studies on the NOTs results and extension workers to focus at most important nutrients in specific location and monitor the end users for getting and applying appropriate fertilizers for their respective areas.

Therefore, this study was planned to identify the main yield-limiting nutrients in wheat crop production through nutrient omission techniques, using different nutrient sources.

2. MATERIAL AND METHODS

2.1. Description of the Study Area

The field experiment was conducted in Welmera district, which is located in West Shewa Zone of Oromia Regional State in Ethiopia. The district is situated at the distance of 29km West of Addis Ababa with altitudes ranging between 2400 meters above sea level.

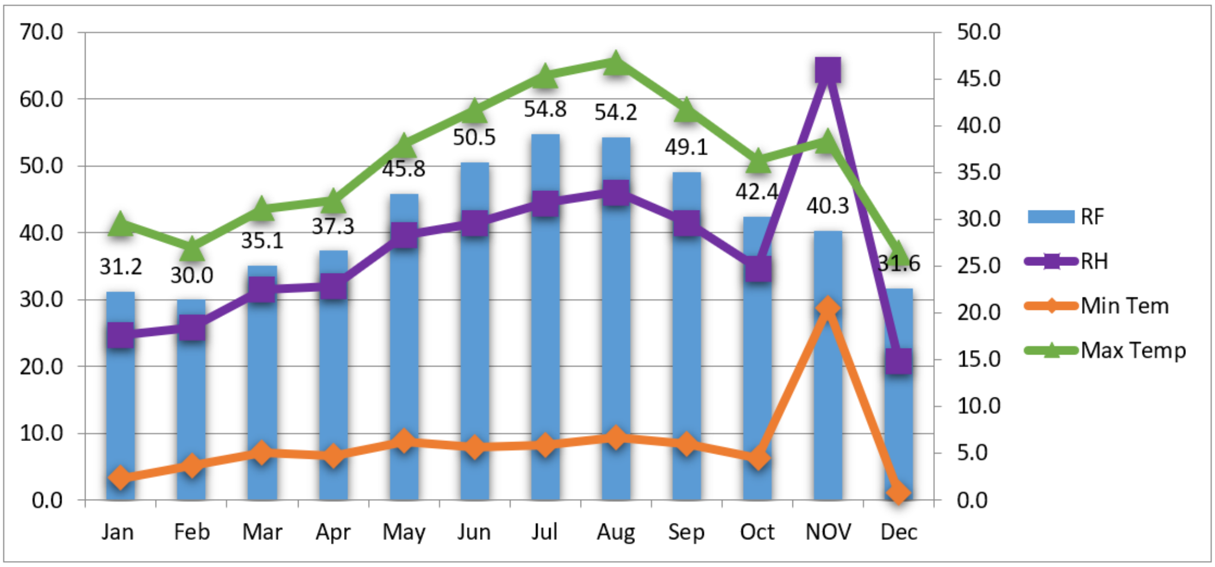

Figure 1: Average Monthly rainfall, temperature and relative humidity for, 2017-2021 of the study site

The study area receives about 1184 mm mean annual rainfall. The rainy season extends from May to October and the maximum rain is received in the months of June to August. The mean annual temperature is about 17.5 oC, with the mean maximum and minimum temperatures of 25oC and 10oC, respectively.

2.2. Site Selection

Sites selected should be representative of the main types of farmers and fields in the area. The field should be easily accessible. The field selected should be of uniform fertility. The field should accommodate all treatments in trial. The minimum distance between farmers field for to be selected for NOTs shall be 500 meter (similar soil types shall be considered).

In the cropping seasons of 2019/2020, nutrient omission trials targeting different nutrient sources were conducted in farmers' fields of West Shawa zone, Oromia region. These trials represented sites with nitisol soil types, in the region. The trials were carried out in Welmera District, West Shewa Zone, by HARC (Holeta Agricultural Research Center), covering high rainfall conditions and Wheat (var.Lemu) was selected as the test crop.

2.3. Experimental Design and Treatment Arrangement

A total of 10 experimental sites were established, with 5 village sites at the district. The experiment was laid out by randomized complete block design (RCBD), using farmers plot as replications per villages. The plot sizes were 3m x 4 m, with spacing between plots and blocks set at 0.5m and 1m, respectively.

The nutrient rates used for the treatments were determined based on research recommendations for crops in high a moisture areas, ensuring the relevance and applicability of the trial results to the local agro-ecological condition. A nutrient rate used for the treatments was based on research recommendations of the crops for high moisture areas.

Table 1: Treatment Arrangement

Trt No	Treatments	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)	B (kg/ha)
1	Control	0	0	0	0	0	0
2	NP (current)	60	69	0	0	0	0
3	PKS(-N)	0	69	40	20	0	0
4	NKS (-P)	60	0	40	20	0	0
5	NPS (-K)	60	69	0	20	0	0
6	NPK (-S)	60	69	40	0	0	0
7	NPKS	60	69	40	20	0	0
8	NPKSZn (-B)	60	69	40	20	5	0
9	NPKSB (-Zn)	60	69	40	20	0	2.5
10	NPKSZnB	60	69	40	20	5	2.5

Table 2: Nutrient type and fertilizer sources

Nutrient	Sources of fertilizers
N	Urea (46% N)
P	(20P=100Kg of TSP)
K	(100 % of KCl=60% of K)
S	100 % of CaSo$_4$=16% of S
B	100 % of borax =11%of B
Zn	100 ZnSo$_4$=35% of Zn

In NOTs make sure that each nutrient rate is non-limiting (slightly above the recommended rate for the area).

Table 3: Treatment description

Treatment	Description
Control	No fertilizer application. Used to measure grain yield as an indicator of the effective indigenous NPK supply from soil, rain water, crop residue and atmosphere.
PK	N omission plot with sufficient P and K amounts applied. Used to measure grain yield as an indicator of the effective indigenous N supply from soil, rain water, crop residue and atmosphere.
NK	P omission plot with sufficient N and K amounts applied. Used to measure grain yield as an indicator of the effective indigenous P supply from soil, rain water, crop residue and atmosphere.
NP	K omission plot with sufficient N and P amounts applied. Used to measure grain yield as an indicator of the effective indigenous K supply from soil, rain water, crop residue and atmosphere.
NPK	Full NPK input to estimate the nutrient limited yield gap and evaluate agronomic use efficiencies of N, P, and K.
NPKSZnB	This treatment will be used to assess the contribution of sulphur and micronutrients (B, Zn) to crop productivity
NPKSZn (-B)	Boron omission plot with sufficient N,P,K and S,Zn to measure yield penalty due to B
NPKSB (-Zn)	Zinc omission plot with sufficient N,P,K and S, B to measure yield penalty due to absence of Zn
NPKZnB (-S)	Sulphur omission plot with sufficient NPK and Zn, B to measure yield penalty due to absence of S

2.4. Soil Samples Collection and Preparation

Soil sampling for the nutrient omission trials involved collecting samples from 0-20 cm depths. These samples were composited separately, considering the field's variability during sample collection, to accurately characterize soil physicochemical properties. By collecting soil samples from several sites and accurately documenting site information, the nutrient omission trials were conducted with a well understanding of the soil environment. This approach enabled researchers to adapt fertilizer recommendations and management practices more effectively, considering the specific soil conditions of each trial site.

2.5. Crop Data Collection

Agronomic data on growth, yield and yield components of the test crop were collected at different times of the growth stage. Growth parameters (Plant height, Spike/panicle length) and yield parameters (biomass, Grain yield, Straw yield) data were recorded. Agronomic efficiency was calculated by dividing the grain yield to the applied nitrogen (Cleemput *et al.*, 2008).

$$\text{AE (kg grain / kgN)} = \frac{\text{Yn} - \text{Yo}}{\text{Fn}}$$

Where, AE= Agronomic efficiency Yn and Yo are the grain yield with or without N applied respectively and Fn is the amount of nitrogen fertilizer applied.

2.6. Data Analysis

The collected soil and agronomic data underwent analysis of variance (ANOVA) using SAS program version 9.1.3 (SAS, 2002). Prior to analysis, outliers were identified and normality of residuals was assessed using the same tool. Significant differences among treatment means were evaluated using the least significant difference test (LSD) at the 0.05 level of probability (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

3.1. Soil Chemical Properties of the Study Site

The pH values indicate slightly acidic to neutral soil conditions (Smith *et al*., 2015). Total Nitrogen (TN) content, shows moderate levels of nitrogen in the soil (Jones & Johnson, 2017). Organic Carbon (OC) content varies from 1.60% to 2.30%, indicating a moderate to high organic matter content in the soil (Brown & Miller, 2018). Available Phosphorus (Av. P) levels range from 17.59 ppm to 41.16 ppm, indicating varying degrees of phosphorus availability in the soil (White & Martinez, 2016). Cation Exchange Capacity (CEC) ranges from 15.92 to 28.28 meq/100g, indicating the soil's ability to retain and exchange cations (Anderson *et al*., 2019).

Table 4: Soil -chemical properties of the experimental sites

Description	pH (1:2.5)	TN(%)	OC (%)	Av. P(ppm)	CEC(meq/100g)
SD	0.41	0.01	0.22	7.34	2.95
SE Mean	0.08	0.003	0.04	1.34	0.54
C.V.	7.35	6.41	11.10	27.84	15.69
Range	5.20-6.47	0.17-0.21	1.60-2.30	17.59-41.16	15.92-28.28

Sd- standard deviation, SE -standard error, CV-co efficient of variation

Potassium (K) content varies from 0.63 to 2.92 cmol (+)/g, indicating varying levels of potassium availability in the soil (Johnson & Wilson, 2020). S-SO_4 (ppm) measured in soil ranged in 5.27 -21.83 ppm) Indicates the availability of sulfur in the soil (Smith & Brown, 2018). Boron in measured in soil ranged 0.12 - 1.02(mg/kg) varying levels of boron availability in the soil, which indicates the need for targeted nutrient management (Miller & Jones, 2017). Zinc in soil measured was ranged from 0.59 - 3.61(mg/kg) Varying level of zinc availability in the soil, which indicates the need for targeted nutrient management practices to optimize crop productivity (Wilson & Martinez, 2021).

Table 5: Soil -chemical properties of the experimental sites

Description	K (cmol(+)/g)	S-So_4	B(mg/kg)	Zn (mg/kg)
SD	0.67	4.08	0.26	0.92
SE Mean	0.13	0.74	0.05	0.17
C.V.	49.035	36.60	55.86	52.24
Range	0.63-2.92	5.27-21.83	0.12-1.02	0.59-3.61

Sd- standard deviation, SE -standard error, CV-co efficient of variation

3.2. Growth and yield components

3.2.1. Response of Nutrient Omission on plant height and spike length of Wheat

This table shows the effects of different nutrient treatments on the plant height (PH) and spike length (SL) of wheat.

Table 6: Response of Nutrient omission on Yield of wheat

Trt no	Nutrient type	PH (cm)	SL (cm)
1	Control	47.67c	3.67b
2	NP (current)	82.6ab	6.54a
3	PKS(-N)	56.3bc	4.6ab

Trt no	Nutrient type	PH (cm)	SL (cm)
4	NKS (-P)	77.47abc	5.87ab
5	NPS (-K)	75.33abc	6.07ab
6	NPK (-S)	85.20ab	6.87a
7	NPKS	89.13a	6.74a
8	NPKSZn (-B)	81.73ab	6.47a
9	NPKSB (-Zn)	91.53a	6.20ab
10	NPKSZnB	89.47a	6.60a
LSD		30.02	2.57
CV		13.21	14.72

Control plot (no added nutrients) resulted in the lowest plant height (47.67 cm) and spike length (3.67 cm). NPKSB (-Zn**)** (missing Zinc) had the highest plant height (91.53 cm). NPK (-S**)** (missing Sulfur) resulted in the longest spike length (6.87 cm). Treatments with a comprehensive set of nutrients (e.g., NPKS, NPKSZnB) generally had the highest values for plant height and spike length.

3.2.2. Response of Nutrient Omission on Yield of Wheat

This table details the effects of different nutrient treatments on the biomass yield (BY) and grain yield (GY) of wheat in the same district. As in Table 7 showed that the lowest biomass yield (6071 kg/ha) and grain yield (1812.5 kg/ha) were recorded from control plot. Whereas, the highest biomass yields (11429 kg/ha) and a high grain yield (3931.0 kg/ha) obtained from NPK (-S) treated plots. Similarly, high biomass yield (11071 kg/ha) and a relatively high grain yield (3809.5 kg/ha) from NPKSZn (-B) treated plots. Therefore, treatments including the full set of nutrients or missing only one nutrient (like S or B) generally resulted in the highest yields.

Table 7: Response of Nutrient omission on Yield of wheat

Trt no	Nutrient type	BY (kg/ha)	GY (kg/ha)
1	Control	6071b	1812.5d
2	NP (current)	11369a	4619.6 a
3	KS(-N)	7143b	2004.9d
4	NKS (-P)	9494a	2922.4c
5	NPS (-K)	10595a	3716.6bc
6	NPK (-S)	11429a	3931.0ab
7	NPKS	10952a	3956.5ab
8	NPKSZn (-B)	11071a	3809.5ab
9	NPKSB (-Zn)	10417a	3475.8bc
10	NPKSZnB	9881a	3467.5bc
LSD		2183.1	881.2
CV		20.70	24.39

The findings from this study align with other research in agronomy and soil science that emphasize the critical role of balanced nutrient management in optimizing wheat yield. For instance, a study by Haile *et al.*, (2012) found that balanced application of NPK significantly increased wheat yield compared to control treatments, similar to the trends observed in Table 7.

Another study by Kumar *et al*., (2019) reported that the omission of key nutrients such as Nitrogen (N) or Phosphorus (P) can drastically reduce wheat yields, approving the lower yields seen in the PKS(-N) and NKS(-P) treatments in this research.

Furthermore, research by Fageria *et al.*, (2011) give emphasis to those secondary nutrients like Sulfur (S) and micronutrients such as Zinc (Zn) and Boron (B) are essential for maximizing crop yields, which is reflected in the higher yields obtained with the NPKSZnB treatment in this study. These findings are consistent with other studies emphasizing the importance of balanced nutrient application for optimal wheat yield.

Haile *et al.*, (2012) found that balanced NPK fertilization significantly increased wheat yield compared to control treatments. This aligns with the higher yields seen in the treatments that included multiple nutrients in the current study. Kumar *et al.*, (2019) reported that the absence of key nutrients like Nitrogen or Phosphorus significantly reduced wheat yields. This supports the lower yields observed in treatments such as PKS (-N) and NKS (-P) in this study. Fageria *et al.*, (2011) highlighted the necessity of secondary nutrients and micronutrients for maximizing crop yield. The high yields in treatments including Sulfur, Zinc, and Boron (e.g., NPKS, NPKSZnB) are in line with these findings.

Control (no added nutrients) resulted in the lowest biomass and grain yield. NPK (-S) (missing Sulfur) produced the highest biomass yield. NP (current) (Nitrogen and Phosphorus) showed the highest grain yield. Generally, treatments including a comprehensive set of nutrients (e.g., NPKS, NPKSZnB) resulted in high yields. These findings are consistent with other studies emphasizing the importance of balanced nutrient application for optimal wheat yield.

Haile *et al*., (2012) found that balanced NPK fertilization significantly increased wheat yield compared to control treatments. This aligns with the higher yields seen in the treatments that included multiple nutrients in the current study. Kumar *et al*., (2019) reported that the absence of key nutrients like Nitrogen or Phosphorus significantly reduced wheat yields. This supports the lower yields observed in treatments such as PKS (-N) and NKS (-P) in this study. Fageria *et al*., (2011) highlighted the necessity of secondary nutrients and micronutrients for maximizing crop yield. The high yields in treatments including Sulfur, Zinc, and Boron (e.g., NPKS, NPKSZnB) are in line with these findings.

3.3. Agronomic Use Efficiency of Wheat as Influenced by Nutrient Sources

The agronomic use efficiency (ANUE) of wheat, as depicted in Figure 2, reveals significant variability across different nutrient sources. This variability gives emphasis to the importance of nutrient management practices in optimizing crop productivity while minimizing environmental impacts. The control treatment exhibited the lowest ANUE, as expected, due to the absence of any added nutrients. The NP treatment showed a significantly higher ANUE compared to the control, underscoring the importance of nitrogen in enhancing grain yield. The PKS (-N) treatment had a considerably lower ANUE compared to treatments that included nitrogen, highlighting nitrogen's critical role in wheat production.

The NKS (-P) treatment demonstrated a reduced ANUE, which emphasizes the essential role of phosphorus in achieving optimal nitrogen use efficiency. In comparison, the NPS (-K) treatment showed a moderate ANUE, indicating that while potassium is important, its absence is less detrimental than the absence of nitrogen or phosphorus.

The NPK (-S) treatment exhibited a high ANUE, suggesting that although sulfur is important, the primary macronutrients (nitrogen, phosphorus, and potassium) have a more significant impact on ANUE. The NPKS treatment demonstrated one of the highest ANUE values, illustrating the synergistic effect of a balanced nutrient application on nitrogen use efficiency.

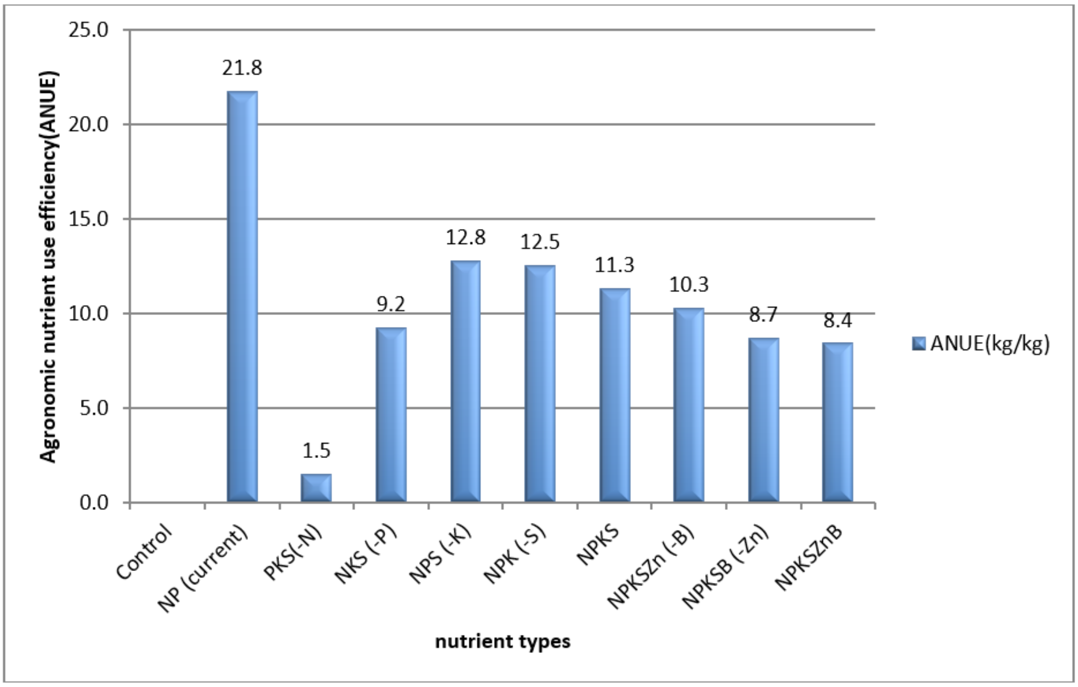

Figure 2: Agronomic nutrient use efficiency of wheat by applying nutrient sources

The treatments NPKSZn (-B) and NPKSB (-Zn) showed slightly lower ANUE compared to NPKS, indicating the roles of micronutrients like zinc and boron in enhancing nutrient use efficiency. The NPKSZnB treatment, which included all nutrients, showed the highest ANUE, reflecting the combined positive effects of comprehensive nutrient application. The results from this study align with findings from other research emphasizing the importance of balanced nutrient management for optimizing wheat yields. Haile *et al*., (2012) demonstrated that balanced NPK fertilization significantly increases nitrogen use efficiency in wheat, consistent with the high ANUE observed in the NP, NPKS, and NPKSZnB treatments in this study. Kumar *et al*., (2019) reported that the omission of key nutrients, such as nitrogen or phosphorus, drastically reduces nitrogen use efficiency. This supports the lower ANUE values observed in the PKS (-N) and NKS (-P) treatments in the current research. Fageria *et al*., (2011) highlighted that secondary nutrients and micronutrients like sulfur, zinc, and boron enhance nutrient use efficiency, corroborating the higher ANUE observed in treatments like NPK(-S), NPKSZn(-B), and NPKSB(-Zn) in this study. In conclusion, Figure 2 emphasizes the importance of a balanced and comprehensive nutrient management strategy to maximize the agronomic nitrogen use efficiency of wheat, consistent with established research findings in the field.

4. CONCLUSION

In conclusion, this study emphasizes the importance of specific nutrient management strategies in overcoming yield limits in wheat production in Ethiopia. Nutrient omission trials successfully identified nitrogen and phosphorus as the primary challenges limiting wheat production in the study area. The findings recommend for the use of balanced fertilization strategies, particularly in high moisture locations, to improve agronomic efficiency and sustain crop yields. Additional research should look investigate regional variations in nutrient requirements and revise fertilizer recommendations to help Ethiopian farmers improve their agricultural output.

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