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Optimizing Sorghum (*Sorghum bicolor*) Yields: A Comprehensive Study of Key Soil Nutrient Deficiencies

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DURING crop cultivation, improper application of fertilizers can lead to an imbalance in soil nutrients, resulting in decreased crop yield and deterioration of soil health. To determine the optimal fertilizer combinations for crops, omission experiments prove to be the most practical and straightforward approach. This research was conducted in the Habru district, specifically in Sirinka kebele, during the 2021/2022 cropping season. The main objective was to identify the nutrients that limit Sorghum (*Sorghum bicolor*) yield through omission trials in the same district. The test crop utilized in the study was the Melkam variety of Sorghum. The various treatments applied nutirnts (N, P, K, S, B, and Zn) were control, NPKSBZn, NPKSZn, NPKSB, NPKBZn, NPSBZn, NKSZn, PKSBZn, and RNP, all arranged in a randomized complete block design (RCBD) with three replications. Prior to the experiment, a composite soil sample was collected from the field to assess crucial factors such as pH, soil texture, organic carbon content, cation exchange capacity, Total N, available P, Exchangeable S, K, Zn, and B. For the analysis of data, the statistical software SAS version 9.3 was employed to conduct variance analysis. The results from the analysis of variance revealed that the treatment with fully fertilized plots (NPKZnSB) achieved the highest grain yield of 4,144.14 kg ha^{-1}. Following closely was the treatment with sulfur omission (NPKZnB) producing 4,100 kg ha^{-1}, whereas the unfertilized treatments only yielded 2,595.32 kg ha^{-1}. In addition to grain yield, the plots treated with NPKSB exhibited the highest agronomic efficiency of N and P. As a consequence, it is imperative for research and development efforts to prioritize nitrogen for achieving optimal sorghum production in the study area. Simultaneously, phosphorus can be strategically employed to maintain optimal fertility levels in the soil. To enhance crop productivity and sustainable agriculture practices, this study highlights the significance of balanced fertilizer application and the importance of understanding the nutrient requirements specific to Sorghum crops in the Habru district. By adopting such knowledge, farmers, and policymakers can make informed decisions and contribute to the overall agricultural development of the region.

Keywords: Nitrogen, Nutrient Efficiency, Nutrient Omission, Phosphorus.

1. Introduction

Sorghum is a cereal crop of significant importance in Ethiopia, ranking third in terms of area covered, after Tef (Eragrostis tef) and maize (Zea mays L.) (CSA, 2023). It is grown in almost all parts of Ethiopia, covering approximately 1.83 million hectares. The national average productivity of sorghum is 2.74 tonnes per hectare. In the North Wollo zone of Ethiopia, sorghum is a major crop alongside Teff, Wheat (Triticum spp.), Barley (Hordeum vulgare), Finger millet (Eleusine coracana), and Oat (Avena sativa), collectively occupying 225,417.2 hectares. Among these, sorghum covers 56,953.3 hectares, accounting for 25.3% of the total cereal crop area (CSA, 2023).

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Ethiopia's economic progress is intricately linked to its agricultural sector. Agriculture forms the backbone of the Ethiopian economy, playing a crucial role in poverty reduction, food security, and overall economic development (Gebremedhin et al., 2023). However, deteriorating soil fertility presents a significant obstacle to agricultural development in Ethiopia. Factors such as increased erosion rates, depletion of biomass and animal manure, and limited application of mineral and organic fertilizers contribute to soil nutrient depletion, a challenge common across several East African countries (Tadesse et al., 2024). Soil fertility assessment is essential for evaluating the levels of inherent and residual nutrients available for plant uptake and determining the optimal amount of fertilizer needed to sustain successful crop production (Berhane et al., 2023). Sorghum productivity faces numerous challenges, including water stress, low soil fertility, inadequate crop management practices, unpredictable rainfall patterns, and pest infestations (Alemu etal.,2024). The improper application of fertilizers can lead to soil nutrient depletion, reduced crop yields, and soil degradation. Thus, maintaining agricultural productivity necessitates the appropriate application of fertilizers to sustain soil nutrients (Gebremedhin etal.2023). Evaluating the nutrient supply capacity of each field before determining the fertilizer requirements is essential to achieving targeted crop yields. One of the most effective and straightforward methods for determining the appropriate fertilizer for a field is the use of omission trials in small plots. This involves a series of small plots, each receiving a full set of all nutrients being evaluated, except for one nutrient, alongside control plots with all nutrients and without any nutrients. Omission trials visibly demonstrate crop response to nutrient availability(Tadesse etal.,2024).In Ethiopia, fertiliser recommendations are typically generalized, with farmers advised to apply a uniform combination of 100 kg DAP and 100 kg urea for all crops, irrespective of specific nutrient requirements (Gebremedhinetal.,2023). This one-size-fits-all approach often results in soil nutrient imbalances, as farmers focus only on fertilizers containing N-P. Continued use of such generalized recommendations can deplete essential soil nutrients and disrupt the overall nutrient balance. Tailored fertilizer application recommendations, considering specific local climate, soil conditions, and management practices, are essential to improve productivity. Determining the optimal intake of macronutrients (N, P, K, S) and micronutrients (Zn, B) based on crop response is crucial for enhancing sorghum productivity. Identifying the primary nutrients limiting sorghum yield is necessary to improve production and productivity in the study area. So this research addressed the following objectives

1. To determine the main nutrients that limit the yield of sorghum (Sorghum bicolor) in the designated area. Additionally, the study aims to measure the absorption and effectiveness of nitrogen and phosphorus nutrients in sorghum (Sorghum bicolor) in the study area.
2. To identify key nutrients that have the greatest impact on the yield of sorghum (Sorghum bicolor) in the specified region. Additionally, it seeks to quantify the absorption and efficiency of nitrogen and phosphorus nutrients in sorghum (Sorghum bicolor) in the study area.

2. Materials and methods

2.1. Description of the Study Area

2.1.1. Location of study district

The study was carried out in the Habiru district, more precisely in the Sirinka kebele. This kebele is located about 12 km north of Woldia town and 18 km from Mersa. Habru Woreda, where the district is located, is one of the Woredas of the Amhara region of Ethiopia. It is found in the northeastern part of the North Wollo Zone, as shown in Figure 1.

2.1.2. Populations

According to the 2007 national census conducted by the Central Statistics Agency of Ethiopia (CSA), Woreda has a population of 192,742. This represents a growth of 14.61% compared to the 1994 census figures. Of the total population, there are 96,874 males and 95,868 females. In addition, there are 21,600 urban residents or 11.21% of the population.

2.1.3. Topography

According to information provided by the District Agricultural Office (2020), Habru has a hilly and mountainous terrain with various altitudes ranging from 700 to 1,900 meters above sea level (m.a.s.l). The topography of the district can be classified into 30% mountains, 35% hilly areas, 25% flat land and 10% gorges or valleys. Similar to the majority of Wollo, Habru has a rugged topography and is located within the watershed boundary of the Abbay, Awash, Tekeze and Golina rivers. Habru Woreda is geographically divided into three agro-ecological zones: lowlands (Kolla), midlands (Woinadega) and highlands (Dega). The highland areas are predominantly inhabited by the majority of the district's population.

2.1.4. Land use and farming system

The Habru Wereda Agricultural Office said the study district includes cultivated land, forest land, pasture land and bare land. The people of Woreda mainly depend on agriculture for their livelihood. They engage in mixed agricultural activities, involving both animal and crop production. Traditional production methods, such as plowing, harvesting and threshing, rely on human and animal labor. While the Kebele lowlands have fertile agricultural land and some Kebeles have access to irrigation from nearby rivers and groundwater sources, agricultural land is limited in the highland areas. The main crops grown in the district are annual crops like sorghum, teff (the dominant crop, especially in the central part of the district) and legumes such as mung beans and field peas. In recent years, some farmers in parts of the district have started cultivating cash crops like onions, tomatoes and other horticultural crops. Although Teff and Sorghum are the predominant crops and main sources of food, income generated from the sale of livestock and livestock products contributes significantly to household food security.

2.1.5. Climate and agro-ecology

In the region, the dominant precipitation regime is bimodal, with two distinct precipitation periods. The main rainy season, called “Kiremt” or prolonged rainy season (meher), extends from late June to early September (Figure 2 and 3). In contrast, the shortest rainy season, known as "Spring", lasts from March to mid-May. The average annual precipitation in the research area amounts to 945 mm, while the average maximum and minimum temperatures are recorded at 26 and 13° Celsius, respectively (Abebe et al., 2022).

2.1.6. Geology and soil

According to the soil classification system established by the Food and Agriculture Organization of the United Nations (FAO, 2007), the study district has four main soil types: Vertisols (20.94%), cambisols (38.06%), regosols (28.08%) and lithosols (12.92%). These soils are characterized as deep to very deep, mainly of alluvial origin, and have moderate to imperfect drainage. The infiltration rate is low, indicating low permeability and high potential for runoff generation. However, the flat topography and nature of the area make it less susceptible to erosion. The geology of Habru Woreda includes sedimentary rock formations. These rocks were formed over time through the deposition and compaction of sediments in ancient environments such as lakes, rivers, and marine settings. They often contain valuable mineral resources and fossils that provide insights into the region's past environments.

2.2. Research Methodology

2.2.1. Experimental materials, treatments and design

The study was carried out during the two main agricultural seasons of 2022 in Habru district, at the Sirinka Agricultural Research Center research site. A high-yielding sorghum variety known as MELKAM, adapted to the lowland areas of Wollo, was chosen as an experimental crop. Soil samples were collected using an auger and core drill before planting and after harvest. The selected site underwent cleaning and preparation, including grading, block formation and plot formation. Particular attention was paid to the representation of cropping systems in the site selection process. The various treatments applied nutirnts (N, P, K, S, B, and Zn) were control, NPKSBZn, NPKSZn, NPKSB, NPKBZn, NPSBZn, NKSZn, PKSBZn, and recommended N combined with P (RNP). The experiment was designed using a randomized complete block design (RCBD) with a plot size of 3 × 4.5 m (13.5 m^2) and three replicates. The spacing between plots and replicates was set at 1 m and 1.5 m, respectively. Sowing took place at the start of the light rains at the beginning of July, with a sowing rate of 10 kg ha^{-1} for row sowing per sowing (Table 1).

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2.3. Methods of Data Collection and Analysis

2.3.1. Soil data collection

Soil samples were collected from typical experimental plots after the removal of plant litter and other debris from the soil surface. The samples were taken in a zigzag pattern to a depth of 0 to 20 cm using an auger. Each sample from the plots was merged to produce a one-kilogram composite soil sample. In addition, undisturbed soil samples of a specified volume were also collected from all plots for bulk density analysis.

The composite soil samples were agitated and then underwent a series of procedures including air drying, thorough mixing, and passing through a 2mm sieve to analyze various parameters. Additionally, a 0.5 mm sieve was used to assess total nitrogen and soil organic carbon levels. The soil analysis was carried out at the soil analysis laboratory of the Debreberhan Agricultural Research Center. To determine the bulk density of the soil, undisturbed soil samples were taken using a core drill and then dried in an oven at 1050°C until a constant weight was reached. The calculation of the apparent density of the soil followed the methodology described by Hillel (2003).

BD= Ms/Vt

Where, ρb = bulk density; Ms = mass of solid (oven dry weight of soil) ; Vt= volume of total soil sample

The pH of the soils was determined in aqueous suspension with a soil-liquid ratio of 1:2.5 using a combined glass-calomel electrode (Van Reeuwijk, 1992). Total nitrogen (N) was quantified by the micro-Kjeldahl digestion method (Jackson, 1958). Available P in the soil samples was extracted following the procedure of Olsen et al. (1954). The soil organic carbon content was assessed using the wet digestion method (Walkley and Black 1934), and the percentage of soil organic matter (OM) was calculated by multiplying the percentage of organic carbon (CO) of the ground by a factor of 1.724. based on the assumption that OM is 58% carbon, as stated by Van Reeuwijk (1992). For the determination of cation exchange capacity (CEC), soil samples were initially leached with 1 M ammonium acetate, washed with ethanol, and then the ammonium was replaced with sodium. Subsequently, CEC was measured titrimetrically by distillation of ammonia replaced by sodium (Chapman, 1965). Available S was analyzed using the FAO turbidimetric method (Ajwa and Tabatabai, 1993), while exchangeable K+ was determined by a flame photometer. The zinc content was evaluated by extraction with diethylene triamine penta-acetic acid (DTPA) according to the procedure developed by Lindsay and Norvell, described by Sahlemedhin and Taye (2000). Available boron was analyzed by extracting the soil with hot water according to the method developed by Berger and Truog (1939).

2.3.2. Yield and yield component of sorghum data collection

The following phonological, yield, and yield components of sorghum crop data were collected.

Aboveground biomass was assessed by measuring the mass of aboveground vegetation in a designated growing area, then standardized to kilograms per hectare. This evaluation involved desiccating a plant sample to a constant weight using an oven temperature of 105°C.

Grain yield assessment involved determining the weight of grains generated by plants in a designated area during the harvest period. Subsequently, this measurement was converted to kilograms per hectare, taking into account the moisture content of the grains, which was adjusted to 12.5%.

Plant height was determined by measuring the distance from the base to the top of the plant at harvest. The average height of ten randomly chosen plants was calculated and presented as the average plant height in centimetres.

The thousand-seed weight was calculated by collecting grain samples from each plot at random and counting a thousand grains. The samples were then weighed to determine the thousand-grain weight in grams.

2.3. Data Analyses

The data obtained on yield, yield parameters, and the uptake of nutrients and use efficiency was analyzed by analysis of variance (ANOVA) using SAS software (version 9.3) to detect variation among treatments. Mean separation was carried out using LSD

Table 2. Detail description of treatments.

No	Treatment	Omitted	Purpose of the treatment
1	NPKSZnB	No ommited	To assess the combined effects of all soil nutrients
2	NPKSZn	Boron (B)	To assess the effect of B on crop yield (minus B plot)
3	NPKSB	Zinc (Zn)	To assess the effect of Zn on crop yield (minus Zn plot)
4	NPKZnB	Sulfur (S)	To assess the effect of S on crop yield (minus S plot)
5	NPSZnB	Potassium (K)	To assess the effect of K on crop yield (minus K plot)
6	NKSZnB	Phosphorus (P)	To assess the effect of P on crop yield (minus P plot)
7	PKSZnB	Nitrogen (N)	To assess the effect of N on crop yield (minus N plot)
8	RNP	Recommended combined N and P doses	
9	No fertilizer	All ommited	Negative control

Abbreviations: N = nitrogen, P = phosphorus, K = potassium, S = sulfur, Zn = zinc, B = boron, RNP = remommended combination of N and P

Rate of applied nutient was N, P_2O_5, K_2O, S, B, and Zn = 92, 69, 100, 30, 1.5, and 5 kg ha^{-1}, respectively

Table 3. Physico-chemical properties of the soil before planting.

Soil parameters	Unit	Value
Sand	%	26
Clay	%	48.5
Silt	%	28.5
Textural class	-	Clay
Bulk Density	g cm^{-3}	1.26
pH	1:2.5 H_2O	6.3
Total Nitrogen	%	0.09
Organic matter (OM)	%	1.96
Available phosphurus	mg kg^{-1}	11.8
Cation exchange capacity (CEC)	$Cmol_{(+)}$ kg^{-1}	17
Exchangeable potassium	$Cmol_{(+)}$ kg^{-1}	1.2
Available sulfur	mg kg^{-1}	5.7
Available zinc	mg kg^{-1}	1.42
Available boron	mg kg^{-1}	0.77

Table 4. Chemical properties of soil after harvesting.

Treatments	T.N (%)	Avail. P (ppm)	S (ppm)	Exch. K (Cmol(+) kg^{-1}	Zn (mg/kg)	B (ppm)	OM (%)	CEC (Cmol(+) kg^{-1})	pH
NPSZnB	0.10	28.57	8.9	1.32	1.67	1.01	1.63	17.80	6.2
PSZnB	0.09	15.37	6.2	1.37	1.42	0.89	1.91	14.70	6.3
NPSB	0.11	12.30	8.2	1.28	1.27	1.19	1.96	21.36	6.2
NSZnB	0.10	14.56	5.2	1.32	1.64	1.11	2.19	22.88	6.4
Control	0.06	14.82	5.3	1.37	1.36	1.78	1.88	15.48	6.3
NPZnB	0.09	21.73	5.9	1.33	1.74	1.10	1.68	18.89	6.4
NPSZn	0.10	13.89	6.6	1.30	1.36	0.93	1.86	16.21	6.3
RNP	0.10	14.31	9.4	1.47	1.31	0.90	1.87	18.75	6.5
NPKSZnB	0.09	20.25	5.5	1.50	2.02	0.94	2.09	18.0	6.5
Mean	0.09	17.31	6.80	1.36	1.53	1.09	1.90	18.22	6.34
SD	0.01	5.22	1.61	0.08	0.25	0.28	0.18	2.67	0.11
LSD	0.015	5.678	1.755	0.082	0.272	0.302	0.191	2.899	0.123

Abbreviations: CEC: cation exchange capacity, TN = total nitrogen, Avail. P = available phosphorus, Exch. K = exchangeable potassium, S = sulfur, Zn = zinc, B = boron, RNP = remommended combination of N and P, OM = organic matter, CEC = cation exchange capacity, SD = standard deviation, Cv = covariance, LSD = least ignificant difference.

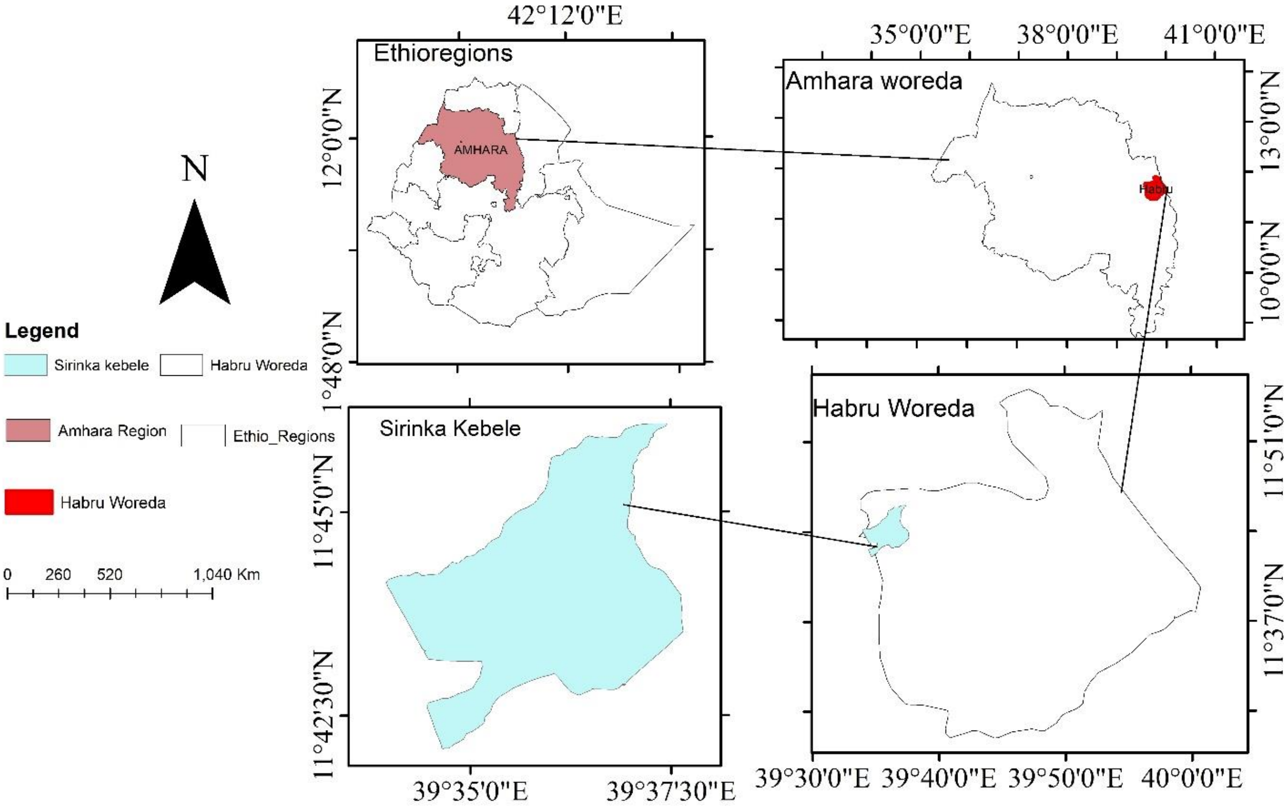

Fig. 1. Study Area Map.

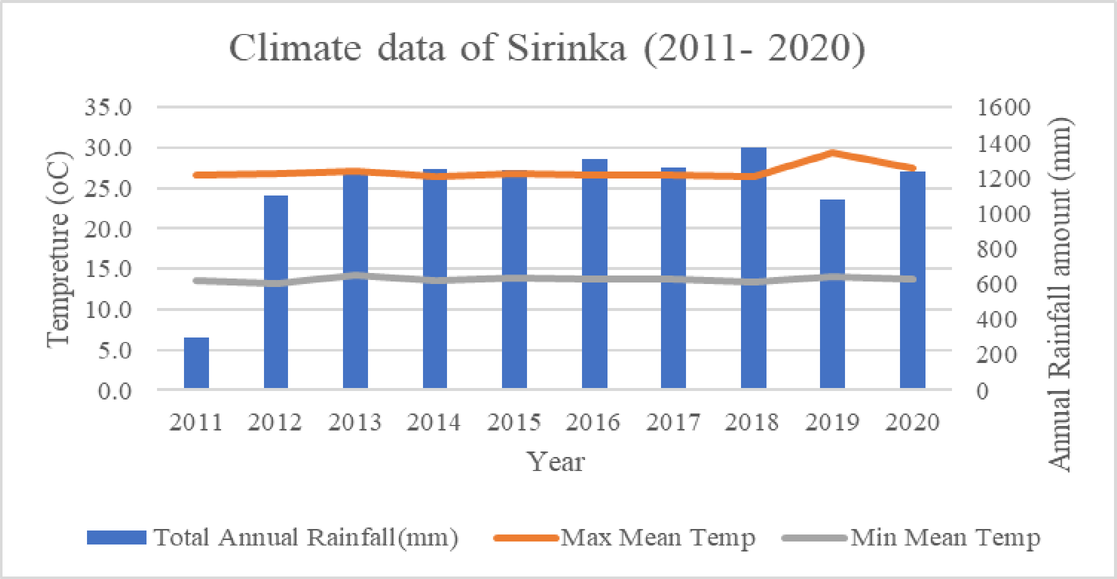

Fig. 2. Annual rain falls, Maximum and Minimum Temperature of the study area (2011-2020). Source (Sirinka Agricultural Research Center (SARC, 2021).

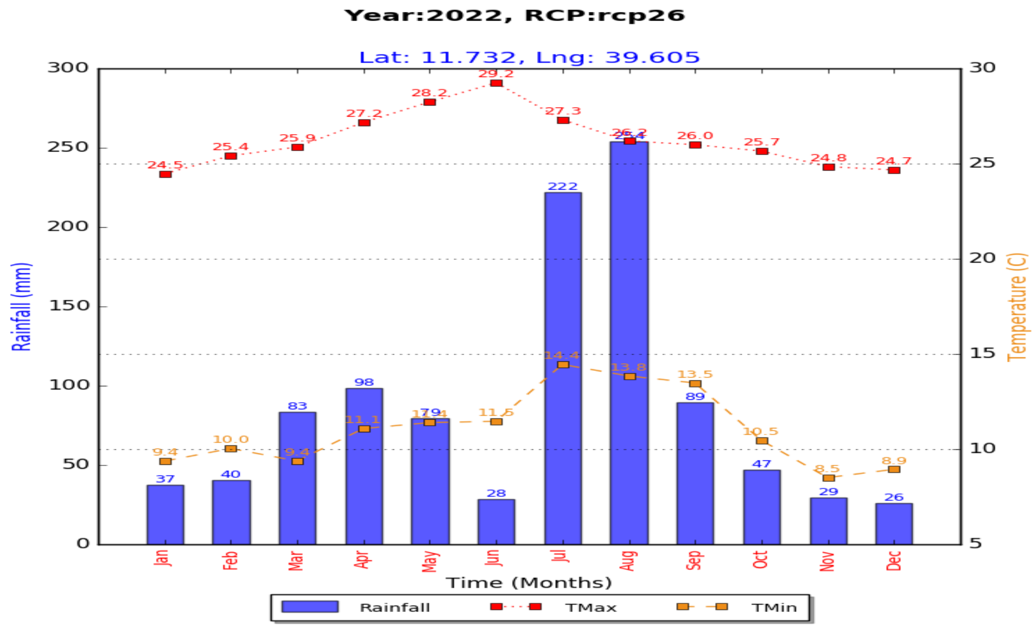

Fig. 3. Rainfall, Maximum and Minimum temperature of the cropping Season.

3. Results

3.1 Initial Soil Characteristics of the Study Sites

3.1.1 Physical properties of soil

Analysis of the particle size distribution of the soil at the study site (Table 2) indicates that the soil is composed of 48.5% clay fractions, 26% sand and 28.5% silt, placing it in the clay texture class according to the USDA classification (1999). This classification is of considerable importance because it greatly influences agricultural production (Jaja, 2016). In addition, this soil has a high water retention capacity. The average apparent density measured was 1.26 g cm-3, suggesting a relatively low density. Therefore, it can be inferred that the soil is suitable for plant growth and seed germination (USDA, 2014). It should be noted that the critical bulk density threshold for clayey soils, beyond which root penetration may be seriously impaired, is 1.4 g cm-3 (Hazelton and Murphy, 2007). Taking into account the favorable apparent density value observed at the experimental site, it can be concluded that the soil belongs to the desired textural class.

3.1.2 Chemical properties of soil

The experimental site had a soil reaction (pH) of 6.3 as shown in Table 2. Tekalign Tadese (1991) classified the soil as slightly acidic. Hamza (2008) suggested that a pH range of 5.5 to 7.0 is optimal for improving plant nutrient availability. Additionally, Horneck et al. (2011) noted that micronutrient deficiencies are rare when soil pH is below 6.5. The total nitrogen (N) content was measured at 0.09%, which corresponds to the low category according to Tekalegn Tadese (1991). Therefore, the application of nitrogen-containing fertilizers is essential in the study area to compensate for the nitrogen deficit that the soil cannot provide to crops. The low N content can be attributed to the continuous and intensive agricultural practices in the region. Hamza (2008) also mentioned that if the organic matter (OM) content is relatively low (1–2%), the soil may lack sufficient nitrogen. The soil organic matter content at the experimental site was determined to be 1.96%, which can be classified as medium/moderate based on the criteria set by Tekalign Tadese (1991). The current amount of OM in the soil may have been obtained through continued agricultural practices that do not involve the incorporation of leftover plant material into the soil. Along similar lines, a study by Fassil and Charles (2009) found that Ethiopian vertisols generally have low levels of soil organic matter. The experimental site had a P content of 11.8 ppm, falling within the high range according to Olsen et al. (1954). The exchangeable K of the site was measured at 1.2 cmolc kg^{-1} of soil, which classifies it as very high according to FAO (2006) standards. Therefore, nutrient K exceeds the level required for optimal crop yield. The CEC of the site was determined to be 17 cmol(+) kg^{-1}, which indicates an average rating according to Hazelton and Murphy (2007). The level of CEC in the soil may be related to the moderate levels of clay and organic matter content present. The analysis of soil parameters before planting, such as pH, total nitrogen, available P, organic matter and texture class, as detailed in Table 2, corresponds to the research results of Abebe Getu et al. (2020) and Wondimu Bayu et al. (2005) carried out in the same area.

The experimental site had a sulfur content of 5.7 ppm, which is considered average according to the study by Horneck et al. (2011). Therefore, the soil at the experimental site can be classified as having moderate sulfur content. The Zn content extractable by DTPA was quantified at 1.42 mg kg-1 according to Table 2. This measurement exceeds the average value of 0.9 mg kg-1 documented for vertisols by Asgelil et al. (2007), as well as the mean value of available Zn (0.5 mg kg-1) reported by Yifru and Mesfin (2013) for vertisols in the central highlands of Ethiopia. As reported by FAO (2008), the soil at the current experimental site is in the average range, characterized by Zn content ranging from 1 to 3 mg kg-1. Horneck et al. (2011) suggest that a soil test result exceeding 1.5 ppm Zn using the DTPA extraction technique is adequate for most crops. The available boron content in the soil at the experimental site was documented at 0.77 ppm. According to Horneck et al. (2011), this places it in the moderate category in terms of availability of soil B content.

3.2 Post-Harvest Soil Characteristics of the Study Site

The post-harvest soil sample pH values were grouped under slightly acidic levels (6.1-6.5) based on Tekalign Tadese (1991) as shown in Table 3.The lack of significant variation in post-harvest soil sample pH values after applying different macro and micronutrients can be attributed to the consistency of pH levels within the slightly acidic range before nutrient application, and the buffering capacity of the soil. The CEC values of all post-harvested soil samples were grouped under moderate (Hazelton and Murphy, 2007). According to Olsen et al., (1954), the rating of available phosphorus after harvesting samples was attained at a higher level. Indicating that the plant was not able to utilize a high amount of phosphorus that was provided by fertilization and that it accumulated on the soil surface. This increment might be also a result of the residual effect of phosphorus fertilization.

According to Tekalign (1991), the post-harvesting result of total N (%) in the study area can be grouped under low range (0.01-0.12%) (Tables 4.2). Application of inorganic fertilizer had no change on total N content, this might be due to the nutrient from this source were readily available for the plant and taken up faster. Like other nutrients, the post-harvesting soil analysis value of OM was rated as medium based on Tekalign (1991). The lowest OM from the pre-planting soil analysis could be due to the continuous utilization of chemical fertilizers (N and P). The decrease in organic matter (OM) levels observed in pre-planting soil analysis could indeed be attributed to the continuous utilization of chemical fertilisers, particularly nitrogen (N) and phosphorus (P).

Overuse of fertilisers without proper organic matter management techniques, such as incorporating organic amendments, can reduce soil organic matter levels over time (Kumar et al., 2021). Conversely, the increase in OM in fully fertilized plots could be attributed to higher OM inputs in the balanced treatment compared to single fertilizer applications. The reduction in OM was more pronounced in plots with single fertilizer applications, while base cation content and pH decreased more in plots with balanced fertilizer treatments (Table 3).

3.3. Yield and Yield Components of Sorghum Response to Applied Nutrients

3.3.1 Biomass yield

For the district's animal feed and fuel wood requirements, biomass sorghum yield holds paramount importance. The utilization of sorghum leaves and stems as cattle feed during the prolonged dry season underscores the critical significance of biomass yield. The findings from the statistical analysis (Table 4) reveal a significant ($p \leq 0.05$) influence of various nutrient applications on the biomass yield of sorghum. Notably, the treatments receiving NPKSZnB and NPKZnB(-S) fertilizers exhibited the highest biomass yield (8585.1 kg ha-1 and 8414.4 kg ha-1, respectively), whereas the control plots yielded the minimum biomass (5697.8 kg ha^{-1}).

Furthermore, it was observed that biomass yield reduction occurred only in the plots where boron (B) was omitted or left unfertilized (control plots). The omission of B led to a 20.15% decrease in biomass yield compared to fully fertilized (NPKSZnB) plots. Conversely, the application of NPSKZnB fertilizer resulted in a significant 33.6% increase in sorghum biomass yield compared to the unfertilized control plot.

Notably, nitrogen (N) plays a crucial role in plant chlorophyll, promoting vegetative growth and enhancing various yield-contributing characteristics. This could explain the observed increase in sorghum biomass as a result of nitrogen application.

The obtained results are consistent with previous studies. Robe and Ibsa (2020) found that NPSZn balanced fertilizer led to the highest biomass yield of sorghum (11,666 kg ha-1) in the Sofi district of Harar regional state. Similarly, Gebremeskel et al. (2017) reported that the application of blended fertilizer with NPSZn under irrigation in Raya Valley, Northern Ethiopia, resulted in the highest biomass yield of sorghum. Workat Sebnie and Merse Mengesha (2018) also observed an increase of 37.07% in sorghum biomass yield with the application of NP fertilizer compared to the control in Wag-Lasta.

The results of this study provide additional evidence for the importance of boron (B) in the growth and development of sorghum. Boron is essential for various physiological functions, such as hormone transport, flowering, activation of salt absorption, pollen germination, fruit development, and pollen tube elongation (Robbertse et al.1990). The decrease in crop biomass under boron deficiency highlights its essential function in stimulating biomass accumulation and, therefore, its importance in improving overall crop yield.

3.3.2 Grain yield

An analysis of variance on grain yield demonstrated that the treatment with zinc (Zn) omitted plots (NPKSB) resulted in a significantly higher grain yield (4144.14 kg/ha), which did not show a statistically significant difference from the sulfur (S) omitted plot (NPKZnB). Conversely, the lowest grain yield (2595.32 kg/ha) was observed in the unfertilized treatments (Table 4). Furthermore, the grain yield from the boron (B) omitted treatment was lower than any other fertilized treatment, although it did not exhibit a statistically significant difference compared to the unfertilized control treatment. The yield obtained from the nitrogen (N) omitted plot was statistically lower than the yield from the NPKSZnB-treated plot but statistically higher than the unfertilized or control plots. The grain yield of treatments excluding phosphorus (P), potassium (K), sulfur (S), zinc (Zn), boron (B), and zinc and boron (Zn&B) showed similarity. Similarly, the yield of the recommended NP treatment was similar to the yield of the excluded treatments P, K, S, Zn, B, and Zn&B, as well as the plot treated with NPSKZnB (Table 2). Furthermore, the grain yield of the recommended NP fertilizer showed no statistically significant difference compared to the application of balanced fertilizer (NPSKZn) and NPSZnB. Nitrogen exclusion resulted in a 23.2% decrease in sorghum grain yield compared to NPSKB treatments, which excluded zinc. The omission of phosphorus, potassium, sulfur, boron, and potassium and boron fertilizers numerically decreased the grain yield of sorghum compared to NPSKB treatments, which also excluded the nutrient zinc and the recommended NP treatment.

The results suggest that nitrogen exclusion results in a notable reduction in yield. The largest decline in crop growth and productivity due to nitrogen absence highlights the critical role of nitrogen application for sorghum, given its status as the most limiting nutrient for crop production. sorghum compared to other nutrients (Mahama et al., 2014). Nevertheless, the exclusion of phosphorus, potassium, sulfur, zinc, boron, and both zinc and boron fertilizers did not have a distinct or statistically significant impact on grain yield when recommended rates of site-specific nitrogen and phosphorus fertilizer treatments were administered. The lower yield observed in plots where nitrogen was omitted implies that other nutrients cannot replace nitrogen in terms of sorghum yield. This phenomenon can be attributed to the influence of nitrogen on chlorophyll synthesis, photosynthesis and assimilated production (Zhou et al., 2011). Unlike the other treatments, the control plots and those without nitrogen experienced the greatest yield losses, indicating insufficient availability of nutrients in the soil to meet the nitrogen requirements of the sorghum crop. Therefore, this research highlights the need for sorghum crops to receive higher nitrogen doses to achieve optimal growth and productivity under rain-fed farming practices in vertisol soil types of the district.

Hazelton and Murphy (2016) stated that the presence of phosphorus in plants decreases when soil pH falls below 5 or is between 8.5 and 9.5. Therefore, the results of this research correspond to the findings of Bereket HaileSelassie et al. (2014), who demonstrate an insignificant impact of phosphate fertilizers in fields with high soil phosphorus levels. This could be attributed to the excessive use of phosphate fertilizers in the study area, leading to the accumulation of phosphorus in the soil (Sharpley, 2000). Crop response and soil test results from this study indicate the accumulation of higher levels of available phosphorus in the district's vertisol soil.

The findings of this study support the research conducted by Yihenew G. Selassie (2015b) on the Alfisol of North-western Ethiopia, which identified nitrogen as the most limiting nutrient for maize production. These results are consistent with Fageria (2014), who recognized nitrogen as one of the primary yield-limiting nutrients in crop production worldwide. Similar conclusions have been drawn in other studies, such as the research by Abebe et al. (2020).

Furthermore, several studies have indicated that the application of new fertilizers, including potassium (K), zinc (Zn), and boron (B), does not significantly limit the yield of maize, wheat, and teff crops in the Northwestern highlands of Ethiopia (Tadele et al., 2018), as well as food barley, bread wheat, and sorghum in North Shewa (Kenzemed et al., 2018), bread wheat in Jamma and Meket district (Habtemariam Teshome et al., 2020), and cotton and sorghum in the Lowlands of North Gondar (Tamrat et al., 2018). These studies consistently highlight the greater limitations on crop productivity imposed by nitrogen and phosphorus nutrients. Additionally, Yihenew G. Selassie et al. (2020) confirmed that potassium (K) is not a yield-limiting nutrient for wheat, tef, and maize in the volcanic soils of West Gojjam and South Gondar Zones of Ethiopia. Similarly, Redai Weldegebriel et al. (2018) noted a lower contribution of boron (B) to sorghum yield increments in Sheraro District, Northern Ethiopia.

In contrast, the work by Hagos et al. (2017) reported higher biological and grain yields of wheat at the highest levels of potassium (K), while Shawl Assefa et al. (2020) emphasized the importance of sulfur (S) as a limiting nutrient for agricultural production in Ethiopian soil. Eyasu et al. (2020) confirmed the grain yield advantage of boron blend fertilizer application compared to an equivalent amount of diammonium phosphate (DAP), and Bereket et al. (2018) highlighted the significance of zinc (Zn) application for maintaining sufficient teff yields. These findings are contrary to the recommendations of the ETHIOSIS soil fertility map (2016), which suggests the application of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), zinc (Zn), and boron (B) fertilizers in the study district. Furthermore, Yifru Abera and Sofiya(2017) reported micronutrient deficiencies as a new challenge affecting crop productivity in Ethiopian soils, which contradicts the results of this study.

3.3.3 Plant height

Statistically, there was no significant difference in the height of the plants among the treatments ($p<0.05$). The analysis of variance (Table 2) revealed that the plots treated with NPKSB fertilizer alone exhibited the tallest plant height (139.8 cm), with no significant difference observed when compared to other treatments, including unfertilized plots. The reduction in plant height due to nutrient omission was evident only when boron-containing fertilizer was not used. Omissions of P, K, S, S, Zn, B, and both Zn and B did not have any significant impact on plant height.

The application of nitrogen, a key nutrient that affects cell elongation and stimulates vegetative growth of plant components, likely contributed significantly to achieving the highest plant height in all treatments, except the control treatment. Conversely, the reduction in plant height observed in the control plots and those deprived of nitrogen could be linked to a nitrogen deficiency and a restricted supply of nutrients to the plants during the growth and development phase of the plant. culture, which would result in inhibited growth.

These results appear to deviate from previous research. In a study conducted by Gebremeskel Gebrekorkos et al. (2017), it was observed that fertilizer application led to an increase in the height of sorghum plants in Raya Valley, Ethiopia. However, another study by Workat and Merse (2018) found that the use of nitrogen and phosphorus fertilizers had a significant impact on the height of sorghum plants in the Wag-Lasta region of Ethiopia. Furthermore, Gebrelibanos and Dereje (2015) found that the lowest and highest plant heights of sorghum were observed in plots without nitrogen application and plots with 150 kg ha-1 nitrogen application, respectively. 'nitrogen.

3.3.4 Leaf length

The analysis of variance showed that leaf length was influenced due to the application of micronutrients and macronutrients ($P < 0.05$) on leaf length compared to N omitted and control plots. The longest leaf length (59.9cm) was recorded from the application of a fully fertilized plot (NPSKZnB), and it is statistically significant from the B omitted and control plots(Table 4). The lowest leaf length is recorded from B omitted and control plots. The longest leaf length was recorded from P omitted plots followed by a fully fertilized plot. The is no significant difference between RNP, N, P, K and S Sulphur omitted plots. The smallest leaf length is recorded from B omitted (50.8cm) and unfertilized plots(52.8cm)(Table 4).

3.3.5 Thousand-seed weight

Analysis of variance demonstrated a statistically significant distinction ($p \leq 0.05$) between the different treatments in terms of thousand sorghum seed weight. Under these circumstances, the highest values for thousand seed weights were observed when S application was omitted (NPKZnB) (Table 4), and this was not significantly different from the treatments receiving NPS and NPSB. On the other hand, the lowest values for thousand seed weights were obtained in the control group, and there were significant differences compared to the application of NPSKZnB, NPS, and NPSB. However, there was no significant difference compared to other treatments (N, P, K, S, B omitted and recommended NP rate). The increase in thousand-grain weight in the NPKSZnB treatment can be mainly attributed to the balanced availability of both nutrients during the grain filling and growth period. According to Kasaye Abera et al. (2020), successful nutrient use can lead to an increase in seed weight to optimal levels, with nitrogen playing a crucial role in promoting the development of greater leaf area. This greater leaf surface area can intercept more light and produce more carbohydrates, which can then be transported to the grain, resulting in higher seed weight. Nigus Demelash et al. (2017) also found that the application of nitrogen fertilizer significantly increased the weight of thousands of grains compared to the control. Similarly, Rawal and Chaurasiya et al. (2018) obtained a similar result for wheat crops, where omitting nutrients did not result in significant differences in thousand-grain weight.

Table 5. Effect of nutrient omission on sorghum yield and yield-related parameters.

No	Treatment	**Parameters**					
		Grain yield (kg/ha)	Biomass (kg/ha)	Thousand Seed Weight	Plant height(cm)	Leaf length(cm)	Grain moisture (%)
1	NPKSZnB	3828.5ab	8585.1a	35.3b	138.5a	59.9a	11.9abc
2	NPKSZn	3370.0abc	6854.8bc	43.3ab	134.8a	50.8c	11.3bc
3	NPKSB	4144.14a	8332.1ab	46.6a	139.8a	52.4bc	11.8abc
4	NPKZnB	4100.07a	8414.4a	41.6ab	138.8a	57.4abc	12.3abc
5	NPSZnB	3283.28abc	7113.7abc	36.6ab	134.2a	52.6abc	14.2ab
6	NKSZnB	3520.01ab	7143.2abc	37.0ab	137.6a	59.5ab	12.2a
7	PKSZnB	3181.49bc	7101.4abc	39.3ab	138.1a	54.3abc	14.2ab
8	RNP	3395.73abc	7591.6ab	41.3ab	137.6a	53.3abc	12.8abc
9	Control	2595.32c	5697.8c	40.0ab	131.2a	52.0c	10.4c
	LSD	*	*	NS	NS	*	*

RCBD: randomized complete block design, CEC: cation exchange capacity, N: Nitrogen, P: Phosphorus, K: Potassium, S: Sulphur, Zn: Zinc, B: Boron, OC: organic carbon, OM: organic matter, DTPA: diethylene triamine penta-acetic acid

3.4. Nutrient use efficiency

3.4.1. Agronomic efficiency of Nitrogen

Based on the use of various nutrients, the average agronomic efficiency of nitrogen (N) ranged from 7.0 to 16.0 kg of grain per kilogram of N applied (Figure 4). The highest average agronomic efficiencies (16 kg of grain per kg of N) were observed in plots where zinc (Zn) was omitted (NPKSB), showing a 34% increase in agronomic efficiency compared to the lowest agronomic efficiency of N in potassium (K) omitted plots (Figure 4). In addition, the agronomic efficiency of N from the recommended NP treatment was higher than that of plots where phosphorus (P), potassium (K), sulfur (S), zinc (Zn), boron (B) and both zinc and boron were present. omitted. The results of this study also suggest that the agronomic efficiency of nitrogen decreased in the following order: omission of Zn > omission of S > fully fertilized > P and recommended NP > B > K. This decrease could be attributed to the lower nitrogen rate in the recommended nitrogen. NP treatment. The results indicate that the omission of potassium (K) significantly reduced the agronomic efficiency of nitrogen, highlighting the importance of potassium supply in improving the agronomic efficiency of nitrogen. The recorded agronomic efficiency of nitrogen is in the range of 5 to 30 kg of grain per kg of nitrogen, which is considered typical of cereal grains, as reported by Dobermann (2005). Additionally, Dobermann noted that nitrogen use efficiency tends to decrease with increasing nitrogen application rates.

3.4.2. Agronomic efficiency of Phosphorous

The mean agronomic efficiency of P ranged from 12 to 31 kg grain kg-1 P applied. P's maximum mean agronomic efficiencies were obtained using Zn omitted plots, with agronomic efficiency increments over the N omitted plot by 61.2% (Figure 4). This increase might be due to the lower rate of P in RNP (46 kg ha-1P2O5) than in others. This indicates a more efficient use of P by Sorghum at a lower rate than a higher rate of P application. Omitting of N reduces the agronomic efficiency of P by 61.2 % from the NPSKB supplied plot(Figure 4). Similar findings on the agronomic efficiency of P for Maize by Tesfaye Balemi et al (2019) confirmed that the omission of nitrogen fertilizer highly reduced AEP on Nitisols of Southwestern Ethiopia**.**

3.4.3 Water Use efficiency

Water-use efficiency (WUE) are essential measure that can affect the productivity of crops in different environmental systems (Asseng et al., 2001). Rainfall use efficiency is the grain yield ratio to rainfall received during the crop growth period. Rain use efficiency (RUE) varied among omission of different nutrients under sorghum production (Figure 5). RUE of Sorghum ranged from 1.9-3.5 kg mm-1, where the highest RUE was recorded at zinc and Sulphur omitted plot (3.1 kg mm-1), and also the lowest RUE was obtained from the control (unfertilized) plot (Figure 5). The increased RUE in the fertilized plot might be due to the impact of fertilizer on growth parameters which helps to suck water from the soil agreement with Turner (2004) stated that fertilizer use has a very pronounced impact on crop yield and rainfall use efficiency.

3.5. Correlation of Yield and Yield Components of Sorghum

Analysis of the relationship between yield components and grain yield revealed significant correlations between all components (Table 5). The data presented in this study demonstrated a highly significant (P < 0.01) positive and linear association between the components of sorghum yield. Specifically, grain yield exhibited a desirable and significantly positive correlation with biomass yield (r=0.98**), plant height (r=0.98**), leaf length (r=0.98**), the weight of a thousand seeds (r=0.98*), and grain moisture (r=0.98**) at P<0.01. Notably, when comparing the correlation coefficients, it was observed that biomass yield displayed a higher correlation coefficient (r=0.99**) compared to other yield components. Moreover, besides grain yield, sorghum biomass yield was significantly correlated with plant height, leaf length, grain moisture, and thousand seed weight at P<0.01. The observed positive correlation between all possible pairs of features suggests the potential for a correlated response, in which improvement in one item would increase the other positively correlated feature.

Improvements in sorghum growth parameters suggest the presence of significant and beneficial relationships between yield and yield components, indicating that improvement in these traits could lead to increased yield due to a strong positive correlation. It is crucial to recognize that this is a key factor in increasing grain yield. The association between grain yield and plant height is consistent with the findings of previous studies (Kassahun et al., 2015; Nguni et al., 2016). The results of the current research support the results reported by Muhidin (2018), who identified very notable and positive links between grain yield and yield components, notably in terms of leaf area index, plant height and biomass yield.

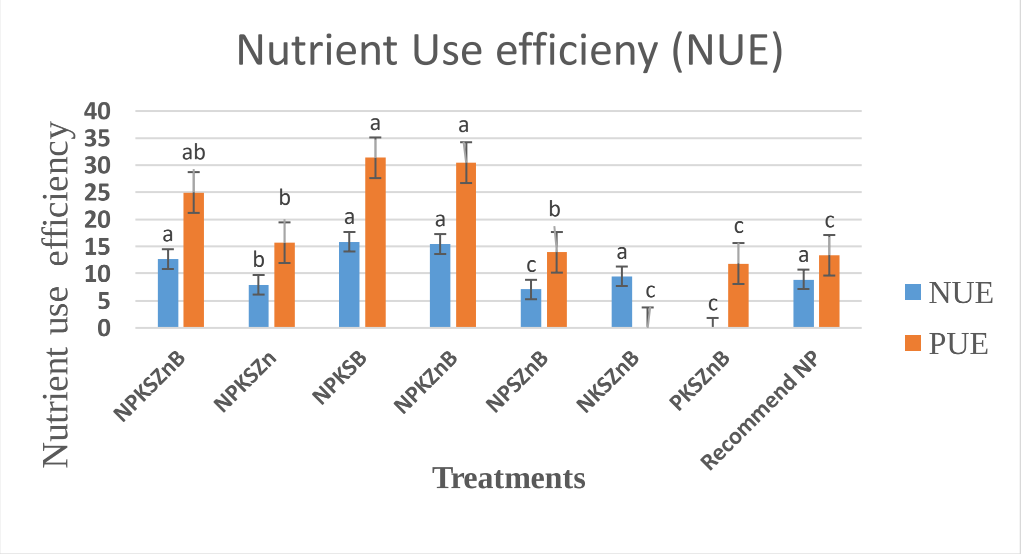

Fig. 4. Agronomic Nitrogen and Phosphorous use efficiency of Sorghum as influenced by nutrient omission (Where; NUE and PUE= Nitrogen and Phosphorous use efficiency, respectively)

N: Nitrogen, P: Phosphorus, K: Potassium, S: Sulphur, Zn: Zinc, B: Boron

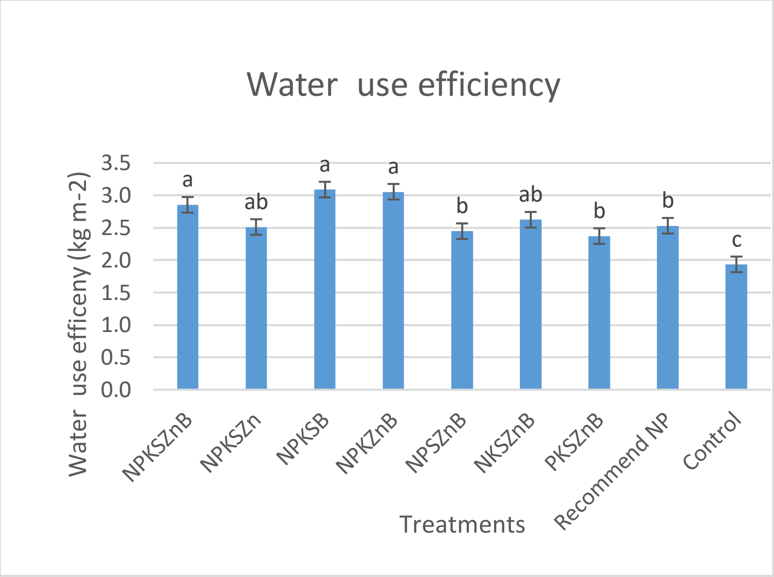

Fig. 5. Water use efficiency is influenced by the nutrient omission.

N: Nitrogen, P: Phosphorus, K: Potassium, S: Sulphur, Zn: Zinc, B: Boron

Table 6. Pearson correlation coefficient between Yield and yield components of Sorghum.

Parameters	PH	LL	BW	GY	TSW	GM
PH	1.00					
LL	0.996^{**}	1.00				
BW	0.990^{**}	0.99^{**}	1.00			
GY	0.98^{**}	0.98^{**}	0.997^{**}	1.00		
TSW	0.99^{**}	0.98^{**}	0.98^{**}	0.98^{**}	1.00	
GM	0.98^{**}	0.99^{**}	0.98^{**}	0.97^{**}	0.97^{**}	1.00

where, ** = significant at $P < 0.05$. PH = Plant Height, LL = leaf Length, GY = Grain Yield BW = Biomass Yield; TSW= Thousand Seed Weight, Gm=Grain Moisture

3.6 Regression of Nutrient uptake and Sorghum yield

The regression analysis between grain yield and nutrient uptake reveals a significant positive relationship. The model's intercept is -36.10, which, while not practically meaningful, sets the baseline for the regression line. The slope of 0.01651, with a standard error of 0.00281, indicates that each unit increase in nutrient uptake is associated with an increase of 0.01651 units in grain yield. This relationship is statistically significant, as evidenced by the t-value of 5.88 and a p-value of 0.00107, which confirms that the slope is significantly different from zero. The model demonstrates a strong fit to the data, with a Pearson correlation coefficient of 0.92309 and an R-squared value of 0.8521, suggesting that approximately 85.21% of the variability in grain yield can be explained by nutrient uptake. The adjusted R-squared value of 0.82745 further supports the model’s robustness, accounting for potential additional predictors. The ANOVA results, with an F-value of 34.57 and a p-value of 0.00107, reinforce the overall significance of the model. However, some data points were excluded from the analysis, which could impact the results. Despite this, the high R-squared value and significant p-values underscore the strong relationship between nutrient uptake and grain yield. Future research should address data completeness and explore additional variables to enhance the model’s predictive accuracy and comprehensiveness (Figure 6).

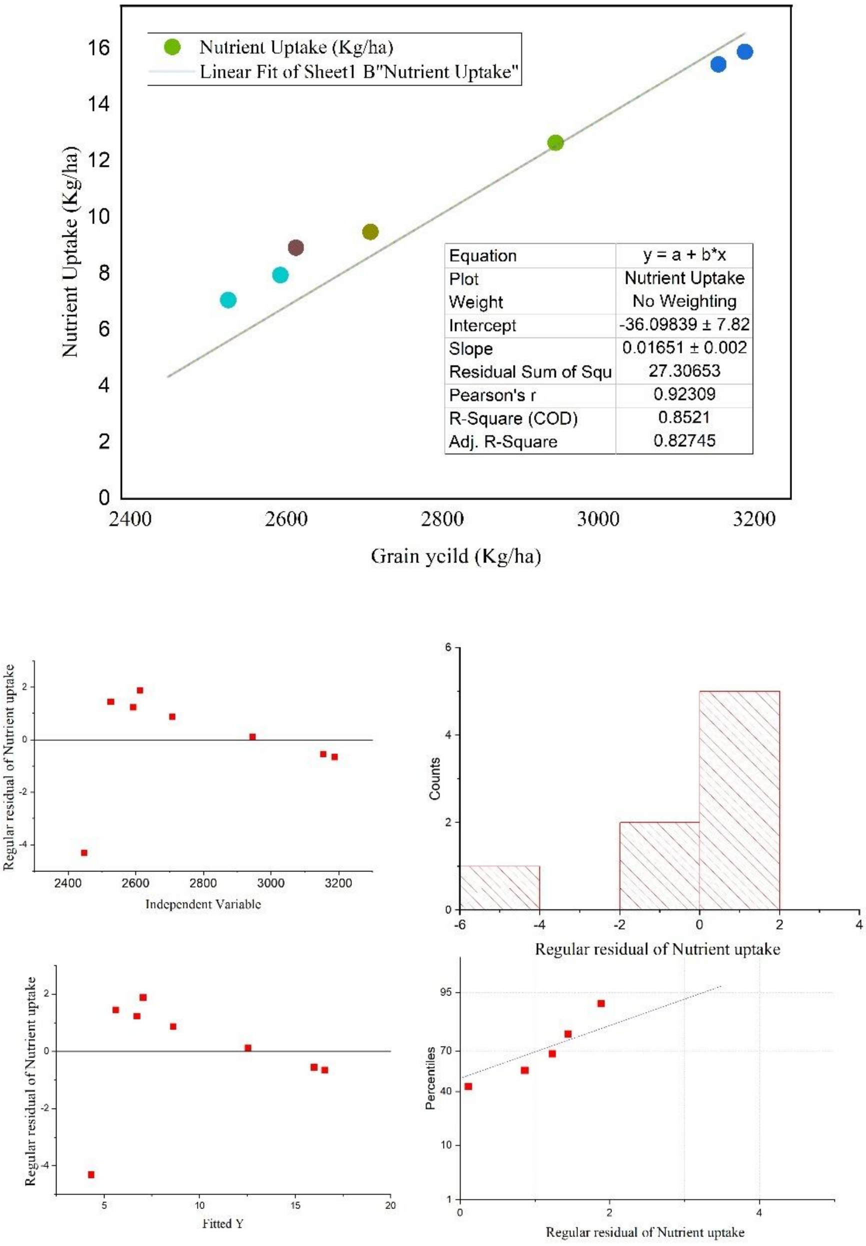

Fig. 6. Regression Analysis of Grain Yield and Nutrient Uptake.

4. Discussion

The soil at the study site is classified as having a clayey texture, with 48.5% clay fractions, 26% sand, and 28.5% silt, making it suitable for plant growth and seed germination. It has a high water retention capacity and an average bulk density of 1.26 g cm-3, considered favorable for soil. The soil reaction (pH) is slightly acidic, with a total nitrogen content of 0.09%, indicating the need for nitrogen fertilizers to compensate for the nitrogen deficit in the soil.

The soil organic matter content is 1.96%, classified as medium/moderate, with a P content of 11.8 ppm. The exchangeable K of the site is 1.2 cmolc kg-1, which is very high according to FAO (2006) standards. The CEC of the site is 17 cmol(+) Kg-1, which indicates an average rating.

The soil has moderate sulfur content, with DTPA extractable Zn content at 1.42 mg kg-1, exceeding the average value of vertisols in Ethiopia. The available boron content is 0.77 ppm, which places it in the moderate category.

The pH values of the post-harvest soil samples are slightly acidic, with no significant variation in the pH values of the post-harvest soil samples after the application of different macro- and micronutrients. The CEC values of all postharvest soil samples are moderate. The lowest OM levels observed in the pre-planting soil test could be due to the continued use of chemical fertilizers, particularly nitrogen (N) and phosphorus (P). Excessive use of fertilizers without proper organic matter management techniques can result in reduced soil organic matter levels over time.

The study focuses on the impact of various nutrient applications on sorghum biomass yield, particularly nitrogen. The highest biomass yield was observed in the treatments receiving NPKSZnB and NPKZnB(-S) fertilizers, while the control plots gave the minimum yield. Nitrogen (N) plays a crucial role in plant chlorophyll, promoting vegetative growth and enhancing yield-contributing traits. This study confirms previous research that NPSZn balanced fertilizer led to the highest sorghum biomass yield in Sofi district, Harar regional state.

The study also found that zinc (Zn) treatment of omitted plots (NPKSB) resulted in significantly higher grain yield (4,144.14 kg/ha), which did not show a statistically significant difference compared to the omitted plot of sulfur (S) (NPKZnB). However, the lowest grain yield (2595.32 kg/ha) was observed in the treatments without fertilization. The nitrogen (N) omitted plot was statistically lower than the NPKSZnB-treated plot, but statistically higher than the unfertilized or control plots.

The results suggest that nitrogen exclusion results in a notable reduction in yield, with the greatest decline in crop growth and productivity due to the absence of nitrogen. The research highlights the need for sorghum crops to receive a higher dose of nitrogen to achieve optimal growth and productivity under rain-fed farming practices in the vertisol soil types of the district.

The study confirms previous research that nitrogen is the most limiting nutrient for corn production, and it is consistent with other studies that have shown that the application of new fertilizers does not significantly limit the crop yield of maize, wheat, and teff in various parts of the country Ethiopia.

The findings of this study align with existing literature on sorghum nutrient requirements, emphasizing the critical role of nitrogen (N) in sorghum productivity. The study shows that nitrogen omission significantly reduces yield, corroborating research that identifies nitrogen as essential for chlorophyll production and vegetative growth. Additionally, the importance of phosphorus (P) and potassium (K) for root development and water regulation is consistent with established knowledge. The study also highlights the significant impact of zinc (Zn) and sulfur (S) on yield, supporting findings that micronutrients are crucial for optimal sorghum growth. Furthermore, the study notes the adverse effects of continuous chemical fertilizer use on soil organic matter, underscoring the need for balanced fertilization practices to maintain soil health (Gebremedhin et al., 2023).

The study compared the application of nitrogen, phosphorus, potassium, sulfur, zinc, and boron fertilizers in Ethiopian soil to determine the impact on crop productivity. The results contradict the recommendations of the ETHIOSE soil fertility map (2016), which suggests the use of these fertilizers. The study found no significant differences in plant height between treatments, with the highest height observed in plots treated with NPKSB fertilizer alone. This research highlights the importance of nitrogen for sorghum productivity, showing significant yield reductions when nitrogen is omitted. To address nutrient imbalances and enhance soil fertility sustainably, integrated soil fertility management (ISFM) practices are essential. ISFM combines chemical fertilizers with organic inputs like compost or manure to improve soil structure and nutrient cycling. Crop rotation and intercropping with legumes can boost soil nitrogen levels, reducing reliance on synthetic fertilizers. Conservation tillage helps minimize soil erosion and maintain organic matter levels. Implementing these practices can lead to more sustainable and productive sorghum farming systems (Gebremedhin et al., 2023; Tadesse et al., 2024).

Reduction in plant height due to nutrient omission was only evident when boron-containing fertilizer was not used. Nitrogen application likely contributed significantly to achieving the highest plant height in all treatments except the control treatment. Leaf length was influenced by micronutrient and macronutrient application, with the longest leaf length recorded in a fully fertilized plot. The study also showed a significant difference in the weight of thousands of sorghum seeds between the different treatments. The highest values for thousand seed weights were observed when S application was omitted (NPKZnB), which was not significantly different from the treatments receiving NPS and NPSB. The increase in the weight of thousands of grains in the NPKSZnB treatment can be attributed to the balanced availability of both nutrients during the grain filling and growth period.

The study analyzed the agronomic efficiency of nitrogen (N) and phosphorus (P) in sorghum production. The average agronomic efficiency of nitrogen ranged between 7.0 and 16.0 kg of grain per kilogram of N applied, with the highest efficiency observed in plots where zinc (Zn) was omitted (NPKSB). The agronomic efficiency of phosphorus (P) was found to be higher in plots where zinc (Zn) was omitted, with an increase in efficiency of 34%. The agronomic effectiveness of phosphorus decreased with increasing nitrogen application rates. The agronomic efficiency of phosphorus increases with the decrease in the P rate in RNP plots. Omitting nitrogen reduced the agronomic effectiveness of phosphorus by 61.2%.

Water use efficiency (RUE) varied with the omission of different nutrients in sorghum production. The highest WUE was recorded in the omitted plots for zinc and sulfur, while the lowest WUE was obtained in the control plot. The study also found significant correlations between yield components and grain yield, with grain yield showing a positive and desirable correlation with biomass yield, plant height, leaf length, seed weight, and grain moisture. This suggests that improvements in sorghum growth parameters could lead to increased yield due to a strong positive correlation.

5. Conclusion and Future Prospective

Appropriate fertilization practices, tailored to the specific nutrient limitations and needs of a given crop, represent a cost-effective and prudent approach to fertilizer use for sustainable agricultural production. To address the current problem of unbalanced fertilizer application and soil depletion at research sites, proactive measures such as avoiding the use of unbalanced fertilizers can help restore soil conditions. soil and improve crop yields. It is crucial to identify soil fertility factors that limit crop productivity, as this knowledge is essential for formulating accurate soil and nutrient management strategies. This move towards soil testing and crop response assessments, rather than relying on generic fertilizer recommendations, applies to various soil types and agroecological zones. The study results suggest that nitrogen deficiency is the main factor limiting sorghum production in the study region. Furthermore, the results indicate that omitting fertilizers containing potassium, sulfur, zinc and boron in addition to the recommended NP fertilizer did not negatively impact sorghum yields. Although these nutrients may become limiting factors in the future, current assessments of soil fertility do not justify their application. Therefore, it is advisable to focus on nitrogen-containing fertilizers supplemented with phosphorus to maintain soil fertility to improve sorghum production and productivity in the study area.

List of abbreviations:

RCBD: randomized complete block design
CEC: cation exchange capacity
N: Nitrogen
P: Phosphorus
K: Potassium
S: Sulphur
Zn: Zinc
B: Boron
OC: organic carbon
OM: organic matter
DTPA: diethylene triamine penta-acetic acid

Declarations

Ethics approval and consent to participate: "Not applicable"

Consent for publication: "Not applicable"

Availability of data and material: The data sets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests: The authors declare that they have no competing interests

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