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Research Article

Identification of Yield-Limiting Nutrients for Sorghum (*Sorghum bicolor* (L.) Moench) Yield, Nutrient Uptake and Use Efficiency on Vertisols of Raya Kobo District, Northeastern Ethiopia

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Agricultural productivity was negatively impacted by low soil fertility and uneven fertilizer application during crop cultivation in Ethiopia. Because of this, important crops frequently respond to fertilizer applications significantly below their achievable and potential yields. This study was carried out to determine the most sorghum yield-limiting nutrients in the Raya Kobo area of the Amhara Region in the 2020/21 crop season. Sorghum variety Girana-One was used as the test crop. Control, NPS, PSBZn, NPBZn, NSBZn, NPSB, NPSZn, NPSBZn, recommended NP, and NPSKBZn were treatments. Three replications of the experiment were used in a randomized complete block design. Before treatment application, a composite soil sample was collected at a depth of 0–20 cm to determine the soil's physicochemical properties. To evaluate N and P uptakes, samples of sorghum stalk and grain were collected. SAS software was used to analyze the data. Results showed that, NPKSZnB produced a considerably greater grain yield (4620 $kg{\cdot}ha^{-1}$), whereas the control and N omitted plots produced the lowest grain yields (2759 $kg{\cdot}ha^{-1}$) and 2805 $kg{\cdot}ha^{-1}$, respectively. Nitrogen fertilizer missing plots showed a statistically significant yield drop compared to the other plots, and there was no statistically significant yield difference between the prescribed NP plots and the potassium, sulfur, boron, or zinc omitted plots. The plots treated with NPKSZnB had the highest agronomic efficiency for N (19.7 kg grain $kg^{-1}{\cdot}N$) and P (10.6 kg grain kg^{-1} P_2O_5). Therefore, research and development should therefore concentrate on nitrogen to achieve the best sorghum yield for the study location. Phosphorus might also be used to keep the fertility level within the ideal range.

1. Introduction

1.1. Background and Justification. Depletion of soil fertility is among the key barriers to agricultural growth in Ethiopia. As a result of high erosion rates, the removal of biomass and animal manure from farmland, and the limited application of inorganic and organic fertilizers nutrient diminution rates are aggravated in the country like many East African countries [1]. In addition, abandoning the traditional practices with natural fallow or uncultivated systems to repair soil fertility and inadequate supply of nutrients are the key constraints and challenges to crop production faced by smallholder growers in Ethiopia [2]. This shows that interventions targeting soil fertility evaluation must be designed to improve the success of crop productivity.

Fertilizers have a significant role in raising crop output, and the careful application of mineral fertilizers is credited with a significant portion of the rise in global food production [3]. In Ethiopia, fertilizer recommendations are based on extremely generic standards for each type of crop, or more frequently, a single recommendation for all crops, which is 100 kg DAP and 100 kg urea [4]. Ignorance of nutrients other than N and P may reduce crop productivity.

Ethiopia is transitioning from blanket recommendations of urea and di-ammonium phosphate towards site, crop, and soil-specific recommendations [5]. According to Tamene et al. [6], more than 2,000 data points that were obtained in the determination of fertilizer responses in Ethiopia, 68.2%, 26.1%, 1.7%, 3.3%, and 0.6% were responses to N, P, K, S, and Zn, respectively. This response was conducted within a test crop of wheat (44.8%), maize (16.1%), teff (10.2%), rice (9.3%), barley (7%), sorghum (3.4%), and pulse crops. Despite recent efforts by EthioSIS to incorporate micronutrients in blend formulations, many fertilizer recommendations are outdated or just include N and P [7].

Unbalanced fertilizer use during crop cultivation will deplete soil nutrients, resulting in a drop in crop productivity and deterioration of soil nutrients [8]. To maintain agricultural productivity, it is crucial to apply the right amount of balanced fertilizer to maintain the soil's nutrients. An omission trial shows the crop's response to nutrient availability in a visible order [9]. Estimates of the crop's capacity to deliver nutrients based on its need as per the target yield from the omission trial revealed an improvement in yields [10].

Productivity is increased with the help of advice for the right fertilizer applications depending on the local climate, soil, and management techniques. However, the need for additional nutrients varies greatly between fields, seasons, and years [11]. In general, fertilizer doses cannot be applied to all crops and fields. Therefore, to boost the productivity of sorghum, it is necessary to quantify the nutrient supply of soils for macronutrients such as nitrogen (N), phosphorus (P), potassium (K), and sulfur (S), as well as micronutrients such as zinc (Zn) and boron (B), and the response of crops to these nutrients. Therefore, it is necessary to determine the nutrients that are most likely to limit yield in the vertisols type of soil in the Raya Kobo district to boost sorghum yield.

2. Materials and Methods

2.1. Description of the Study Area. The trial was conducted on the vertisols type of soil, of the Raya Kobo district, located at 12°09′N latitude and 39°38′E longitude and has a 1468 masl elevation (Figure 1).

The principal feature of rainfall (RF) in the district is bimodal, with two distinct rainfall seasons. Based on the data from Kobo meteorological station during the last twenty years (2001–2020) (Figure 2) rainfall pattern is characterized by seasonal, poor distribution, and erratic.

2.2. Research Methodology

2.2.1. Experimental Materials. The experiment was carried out over the key crop seasons of 2020/21 on the farmers' land at Raya-Kobo district. High yielding and early maturing sorghum variety (Girana-One) was used as a test crop.

2.2.2. Experimental Design and Treatments. The experiment consists of ten treatments, as described in Tables 1 and 2 and organized in a randomized complete block design (RCBD) with three replications. The spacing among plots and replication was 1 m. Planting was made at the onset of the short rain in mid-July 2020 in a row by drilling. The gross sizes of the plots were 4.5 m × 3 m (13.5 m^2) in six rows per plot. The spacing between plants was 15 cm, and the distance between rows was 75 cm. Two weeks after germination and emergence, one seedling per hill was thinned out.

2.2.3. Nutrient Source and Application Method. Phosphorus, potassium, boron, sulfur, and zinc were applied at planting as triple super phosphate (TSP), potassium chloride (KCl), borax, calcium sulfate, and zinc oxide, respectively. For all N containing treatments half of N contain fertilizer (Urea) was applied at planting and the remaining half of N fertilizers were applied at 45 days after planting just after weeding with the presence of small rainfall. All recommended practices were done during the development period of sorghum. Beginning in the first week of November and continuing until mid-November, harvesting and threshing took place.

2.3. Data Collection and Analysis

2.3.1. Collection of Soil Samples and Analyzes. After clearing the soil surface of any debris and plant litter, soil samples were collected from representative experimental plots before planting. Using a soil auger, soil samples were taken in a zigzag pattern from 0 to 20 cm deep. Each soil sample taken from the test plots was bulked to create a single composite soil sample weighing one kilogram. To evaluate the soil bulk density, additional undisturbed soil core samples with known volumes were taken from all plots.

The bulk density of the soil was calculated after drying of the soil sample at 105°C in an oven until a constant weight was recorded [12] and calculated as follows:

$$\rho\text{b} = \frac{Ms}{Vt}, \tag{1}$$

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

Potentiometric analysis was used to determine the pH of the soils in water suspension at a ratio of 1 : 2.5 (soil to liquid) [13]. The micro-Kjeldahl digestion method was used to calculate total nitrogen (TN) [14]. Olsen et al. [15] was used for the determination of available P from the soil sample. Using the wet digestion method, the soil's organic carbon content was examined [16]. Titrimetrically, CEC was determined by distilling the ammonia that sodium replaced [17]. Ajwa and Tabatabai [18] used the FAO-turbidimetric approach to analyze the available S and a flame photometer to assess the exchangeable K^+. Diethylene triamine pentaacetic acid (DTPA) extraction was used to quantify zinc using the method created by Lindsay and Norvell and described by Sertus and Bekelye [19]. Berger and Truog [20] method of hot water extraction of soil was used to determine the amount of available boron.

2.3.2. Data Collection and Measurements on Yield and Yield Components. Soil plant analysis development (SPAD) value, plant height, above ground biomass, and Grain yield were collected as follow:

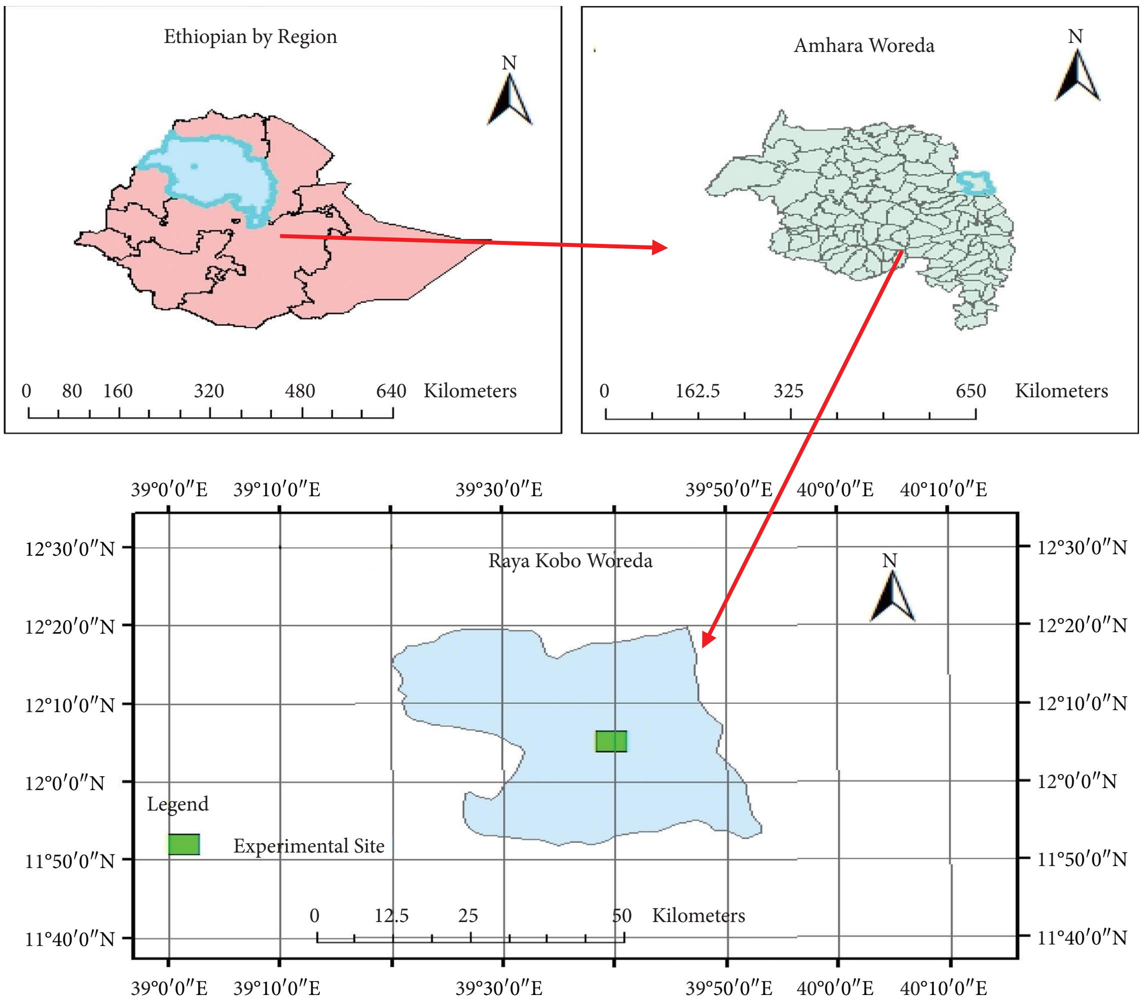

Figure 1: Location of Raya kobo woreda.

SPAD value: SPAD-502 chlorophyll portable meter (Minolta, Osaka, Japan) was used to measure the SPAD value of sorghum by taking fully developed leaves, and then three places were selected from five plants to take the average from a stage of flower initiation. All chlorophyll meter readings were taken midway between the stalk and the tip of the leaf.

Plant height: The height of the plants was measured at harvest from the base of the plant to the top. Average values of randomly selected plants were measured and expressed as mean plant height in centimeters.

Above ground biomass: It was measured by taking the weight of the above ground biomass of plants in a plot at maturity and converting it to kg per hectare. It was adjusted by drying a sample of plants until a constant weight is attained with oven (at 105°C).

Grain yield: It was measured by taking the weight of the grains for plants in a plot at harvest and converting it to kg per hectare after adjusting the grain to 12.5% moisture content.

2.3.3. Grain and Stalk Sampling Analyzes. The above ground parts of sorghum were cut at ground level at the harvesting stage, and representative stands were taken in each central plot randomly for both grain and stalk nutrient content analysis. The stalk and grain samples were analyzed for nutrient for total N and P from each plot separately. The wet-oxidation procedure of the Kjeldahl methods and dry ashing method were used for N and P content determination.

2.3.4. Estimation of Total N and P Uptake. Nitrogen uptake: It was calculated by multiplying the respective stalk and grain yields by the N concentration. The N and P uptake of the grain and the stalk were added to determine the total N and P uptake.

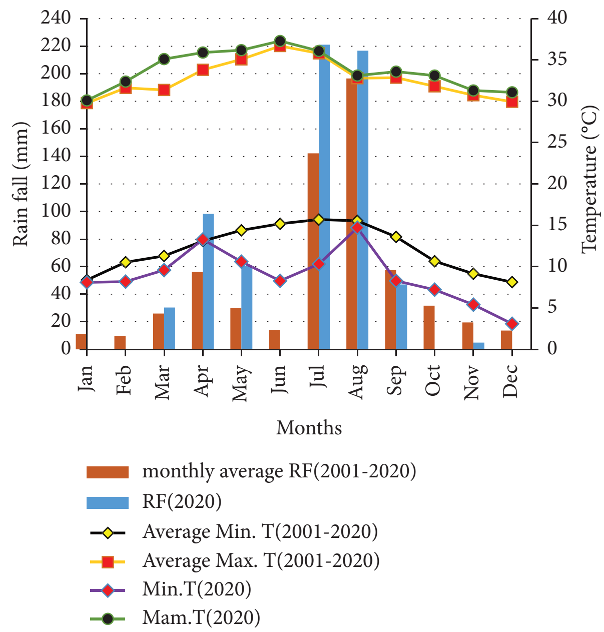

Figure 2: Mean monthly temperature and rainfall of Raya Kobo district in 2020 cropping season (source: Kobo meteorological station).

The following empirical formula was used for nutrient uptake determination: as stated by Weldegebriel et al. [21].

$$\text{Nutrient uptake by Grain or Stalk}\left(\frac{\text{Kg}}{\text{ha}}\right) = \frac{(\text{GY or SY (Kg/ha)} * \text{ Nutrient concentration})}{100}, \tag{2}$$

where GY is grain yield and SY is stalk yield.

2.3.5. Nutrient Use Efficiency. The yield increase per applied unit of nutrient is used to calculate agronomic efficiency (AE). Agronomic use efficiencies of N or P fertilizer nutrient (AEN) are calculated using the procedure designated by Dobermann [22] as cited by [23]

$$\text{AE}\left(\frac{\text{kg grain}}{\text{kg nutrient}}\right) = \frac{\text{Grain Yield (Kg/ha)}F - \text{Grain Yield (Kg/ha)}i0}{\text{nutrient applied (Kg/ha)}}, \tag{3}$$

where F is fertilized treatment; and io is the treatment i nutrient omitted.

2.4. Statistical Analysis. To find differences across treatments, the collected data on yield, yield metrics, and nutrient uptake and use efficiency were subjected to an ANOVA analysis using SAS software (version 9.3). The Duncan Multiple Range Test (DMRT) was used to distinguish between significant treatments means, with a 5% level of significance. The Gomez and Gomez [24] method was used to calculate the correlation between the parameters in order to determine the association between yield and yield components.

3. Results and Discussion

3.1. Initial Soil Property of the Trial Site

3.1.1. Selected Physical Properties of the Soil. The result of the soil particle size distribution analysis of the study site (Table 3) indicated that the soil has 47.5% clay, 25% sand, and 27.5% silt fractions, which are categorized under the clay textural class [25]. This textural class is one of the most important soil characteristics and has a significant effect on crop production [26]. High water holding capacity is the characteristics of such type of soil. The average bulk density was 1.26 g/cm^3 which are relatively low. This implies that the soil is good for plant growth and seed germination [27]. For

Table 1: Description of treatments and its purpose.

S.N	Treatment	Purpose of the treatment
1	Control (no fertilizer)	Negative control
2	Phosphorus, sulfur, boron, zinc (PSBZn)	To assess the effect of N on crop yield (minus N plot)
3	Nitrogen, sulfur, boron, and zinc (NSBZn)	To assess the effect of P on crop yield (minus P plot)
4	Nitrogen, phosphorus, sulfur, boron, and zinc (NPSBZn)	To assess the effect of K on crop yield (minus K plot)
5	Nitrogen, phosphorus, and sulfur (NPS)	To assess the effect of Zn, K, and B on crop yield (minus Zn, B, and K plot)
6	Nitrogen, phosphorus, sulfur, and boron (NPSB)	To assess the effect of Zn on crop yield (minus Zn plot)
7	Nitrogen, phosphorus, sulfur, and zinc (NPSZn)	To assess the effect of B on crop yield (minus B plot)
8	Nitrogen, phosphorus, sulfur potassium, boron, and zinc (NPSKBZn)	To assess the effect of all nutrients on crop yield (no nutrient is limiting)
9	Nitrogen, phosphorus, boron, and zinc (NPBZn)	To assess the effect of S on crop yield (minus S plot)
10	Recommended fertilizer (RD)	Site-specific recommended (N&P)

Table 2: Description of fertilizer rate applied in trial.

S.N	Treatments	Applied nutrient ($kg{\cdot}ha^{-1}$)						
		N	P_2O_5	K_2O	S	B	Zn	Remark
1	Control	0	0	0	0	0	0	All omitted
2	PSBZn	0	69	0	30	1.5	5	N and K omitted
3	NSBZn	92	0	0	30	1.5	5	P and K omitted
4	NPSBZn	92	69	0	30	1.5	5	K omitted
5	NPS	92	69	0	30	0	0	K, Zn, and B omitted
6	NPSB	92	69	0	30	1.5	0	K and Zn omitted
7	NPSZn	92	69	0	30	0	5	K and B omitted
8	NPSKBZn	92	69	60	30	1.5	5	Full applied
9	NPBZn	92	69	0	0	1.5	5	K and S omitted
10	RD	69	46	0	0	0	0	K, S, B, and Zn omitted

Table 3: Selected physicochemical property of the soil (before planting).

Soil parameters	Units	Values
Sand	%	25
Clay	%	47.5
Silt	%	27.5
Texture	—	Clay
Bulk density	g/cm^3	1.26
Ph	1 : 2.5 H_2O	6.3
Total nitrogen (TN)	%	0.09
Organic matter (OM)	%	1.96
Available phosphorus	ppm	11.8
CEC	Cmol $(_+)$ kg^{-1}	17
Exch. potassium	Cmol $(_+)$ kg^{-1}	1.2
Available sulfur	ppm	5.7
Zinc	mg kg^{-1}	1.42
Boron	ppm	0.77

clay soils, 1.4 $g{\cdot}cm^{-3}$ is the threshold value of bulk density for plant growth at which root penetration is expected to be severely constrained [28]. Following this critical value for clay texture, the stated bulk density value of the trial site is in the favorable soil textural class.

3.1.2. Selected Soil Chemical Properties. The experimental site's soil response (pH) was 6.3 (Table 3). Based on Tadese [29], the soil was slightly acidic. According to Hamza [30], the pH range of 5.5 to 7.0 appears to be ideal for enhancing plant nutrient availability. In addition, according to Horneck et al. [31] micronutrient deficiencies rarely occur when the soil pH is below 6.5. According to Tadese [29] rating, the total nitrogen content was rated as low (0.09%). Thus, to replenish the leftover nitrogen that the soil was unable to provide to the crop in the study region, nitrogen-containing fertilizer must be applied. The lower N content might be due to the continuous and intensive cultivation system in the district. Hamza [30] also reported that if organic matter is relatively low (1-2%), then there may not be enough nitrogen in the soil. The SOM content of the experimental site was 1.96%, which can be considered medium/moderate as per the ratings of Tadese [29]. This level of OM may be the result of ongoing agriculture without adding leftover material to the soil. The OM content of Ethiopian vertisols was low [32]. According to Olsen et al. [15] rating, the experimental site's available phosphorus content was 11.8 ppm, which is categorized in the high range. The exchangeable potassium for the experimental site was 1.2 cmol $(_+)$ kg^{-1} soil, which is classified as very high according to FAO [33]. Thus, the nutrient potassium is considered more than the adequate level in the study site and will not limit crop yield.

Table 4: Effect of nutrient omission on sorghum SPAD value and plant height.

Treatments	Parameters	
	SPAD values	Plant height (cm)
Control	37.1^{c}	208.9^{b}
PSZnB (−N)	38.3^{bc}	206.4^{b}
NSZnB (−P)	41.9^{abc}	231^{a}
NPSZnB (−K)	46.0^{a}	233.6^{a}
NPZnB (−S)	46.2^{a}	235.9^{a}
NPSZn (−B)	43.1^{ab}	242.8^{a}
NPSB (−Zn)	44.9^{a}	238.3^{a}
NPS (−ZnB)	44.6^{a}	245.4^{a}
RNP	44.3^{a}	230.2^{a}
NPKSZnB	45.0^{a}	234.5^{a}
Sign.Level	*	**
CV (%)	6.9	5.1

N.B: means in the columns that are denoted by the same letter do not differ substantially at $P \leq 0.05$.

The CEC of the experimental site was 17 cmol $(_+)$ kg^{-1} which is rated as medium based on Hazelton and Murphy [28] rating. According to those authors, a CEC value between 12 and 25 cmol $(_+)$ kg^{-1} is rated as a medium. This amount of CEC in soils of the trial area could be associated with moderate levels of clay and the OM content of the soil. The analysis of the preplanting soil (pH, total N., avail. P, OM, and textural class) result (Table 3) is in line with the soil test outcomes of Getu et al. [34] and Bayu et al. [16] in the same district.

The available sulfur content of the experimental site was 5.7 ppm. According to Horneck et al. [31] rating soils with 5–20 ppm content of sulfur are grouped as medium. The DTPA extractable Zn content was 1.42 $mg{\cdot}kg^{-1}$ (Table 3).

The greater levels of Zn in the soil than the average (0.9 $mg{\cdot}kg^{-1}$) was reported by Asgelil et al. [35]. The greater levels of Zn in vertisols type of soil in Ethiopia were also observed by Yifru and Mesfin.

According to FAO [36], the soil of the present experimental area was grouped as a medium, which is between 1 and 3 $mg{\cdot}kg^{-1}$. According to Horneck et al. [31]; for most crops, a soil test with zinc levels above 1.5 ppm using the DTPA extraction method is sufficient. The available boron recorded at the trial site was 0.77 ppm. Based on Horneck et al. [31], the availability of soil boron content of the present experimental site was categorized under moderate class.

Table 5: Effects of omission of nutrient on grain yield and above ground biomass yield of sorghum.

Treatments	Biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
Control	8892^{b}	2759^{c}
PSZnB (−N)	9449^{b}	2805^{c}
NSZnB (−P)	15785^{a}	3887^{b}
NPSZnB (−K)	17286^{a}	4504^{ab}
NPZnB (−S)	15835^{a}	4091^{ab}
NPSZn (−B)	19180^{a}	4472^{ab}
NPSB (−Zn)	18989^{a}	4168^{ab}
NPS (−ZnB)	16202^{a}	4238^{ab}
RNP	15980^{a}	4087^{ab}
NPKSZnB	17985^{a}	4620^{a}
Sign.Level	**	**
CV (%)	11.5	8.8

N.B: means in the columns that are denoted by the same letter do not differ substantially at $P \leq 0.05$. Where ** = significant at $P \leq 0.01$, * = significant at $P \leq 0.05$.

3.2. Sorghum Yield and Yield Components Response to Applied Nutrients

3.2.1. Soil Plant Analysis Development (SPAD) Value. The treatment of various fertilizers had a substantial ($P \leq 0.05$) impact on SPAD value. The SPAD reading was not significantly different in N containing plots, where the highest SPAD value (46.2) was recorded from S omitted plots while the lowest chlorophyll content (37.1) was obtained from unfertilized treatments (Table 4). N omitted plots had a significantly lower SPAD value than K, S, Zn, and both Zn and B omitted plots and from plots that received RNP and NPSKZnB. Increasing the SPAD value due to N would be associated with the higher nitrogen accumulation of sorghum leaves that ultimately donated to the synthesis of chlorophyll. According to this finding, Ajeigbe et al. [37] indicated that the maximum SPAD value was discovered to be between 80 and 100 kg·N·ha^{-1} in the Nigerian BUK and Minjibir. Those authors relate SPAD value with the nutrient supply capacity of the soil. Rostami et al. [38]; stated the SPAD measurements were significantly increased with N application in maize crop.

3.2.2. Plant Height. Plant height varied significantly ($P \leq 0.05$) between treatments. The longest height of the plant (245.4 cm) was obtained from the application of NPS fertilizer, which showed a significant difference between nitrogen omitted and control (unfertilized) plots. These plots had the lowest plant height than the other N-containing treatments (Table 4). Thus the plant height reduction was observed in plots where nitrogen fertilizer was omitted. On average nitrogen omitted plots had a 15.9% height reduction as compared with NPS fertilized plots. Plant height in the plots of P, K, S, Zn, and B and both Zn and B omitted treatments were not significantly varied. The highest plant height in all the treatments except in the N omitted and control plots was the result of the application of nitrogen. While the reduction in plant height under the control and N omitted plots might be associated with the deficiency of nitrogen or inaccessibility of the nutrient to the plant. In line with these results, Gebrekorkos et al. [39] described that the application of fertilizer increases plant height of sorghum in Raya valley Ethiopia. In line with this result, Sebnie and Mengesha, [40] also stated that nitrogen and phosphorus fertilizers significantly affect the plant height of sorghum in the Wag-Lasta area of Ethiopia. In addition, Gebremariam and Assefa [41] also informed that the lowest and the maximum plant height of sorghum was attained from plots without nitrogen application and from 150 kg·ha^{-1} nitrogen, respectively.

Table 6: Agronomic nitrogen and phosphorus efficiency of sorghum as influenced by omission of nutrients.

S/n	Treatments	AE_N	AE_P
1	PSZnB (−N)	—	−15.7
2	NSZnB (−P)	11.8	—
3	NPSZnB (−K)	18.5	8.9
4	NPZnB (−S)	13.9	3.0
5	NPSZn (−B)	18.1	8.5
6	NPSB (−Zn)	14.8	4.1
7	NPS (−ZnB)	15.6	5.1
8	RNP	18.6	4.3
9	NPKSZnB	19.7	10.6

Where AE_N and AE_P = nitrogen and phosphorus agronomic efficiency respectively.

3.2.3. Above Ground Biomass Yield. The statistical analysis showed that the application of different nutrients had a significant impact on the biomass yield of sorghum. The lowest biomass yield (8892 kg·ha^{-1} and 9449 kg·ha^{-1}) was attained from the unfertilized plots and N omitted plots, respectively (Table 5). The omission of P, K, S, Zn, B, Zn, and B and the recommended NP didn't show a significant reduction in biomass yield of sorghum as compared with the fully fertilized plot (NPKSZnB). This similar or non-significant output of sorghum biomass was the result of the nutrient nitrogen as it is responsible for vegetative growth and medium to high initial soil nutrients except nitrogen (Table 3) in the study site. However, the biomass yield decline was detected only from N omitted plots and unfertilized (control) plots. The omission of nitrogen reduces biomass yield by 50.7% and 47.5% from boron omitted and fully fertilized (NPKSZnB) plots, respectively. However, compared to the control (unfertilized) plot, the application of NPSKZnB fertilizer boosted the sorghum biomass output by 50.5%.

This outcome was consistent with the findings of Robe and Ibsa [42], who showed the highest biomass yield (11,666 kg·ha^{-1}) of sorghum was recorded after NPSZn application in the Sofi district of Eastern Ethiopia. Similarly, Gebrekorkos, et al. [39] stated the most elevated sorghum biomass yield was obtained after the application of NPSZn in the irrigated agriculture of Raya valley, Northern Ethiopia.

3.2.4. Grain Yield. The results of the analysis of variance revealed that nutrient omission had a substantial impact on the grain production of sorghum. Reduced grain yield

(2759 kg·ha^{-1}) on control plots was noted, which was not statically different from the N and P omitted plots (Table 5). In addition to unfertilized plots, grain yields obtained from N omitted treatments were lower than any other fertilized treatments. The Grain yield obtained from recommended NP treatment was at par with P, K, S, Zn, B, both Zn and B omitted plots, and NPSKZnB treated plots (Table 5). The omission of N resulted in a 39.3% decrease in sorghum grain yield as compared to NPSKZnB treated plots. The maximum decrease in crop growth and productivity owing to the omission of N emphasized the importance of N nutrient to sorghum, which is the most limiting nutrient for sorghum production over other nutrients [43]. But, the omission of phosphorus, potassium, sulfur, zinc, boron, and both zinc and boron fertilizers did not show a clear and statistically significant impact on grain yield with site-specific recommended rates of fertilizer. The lowest yield in N omitted plots indicates that the application of nitrogen cannot be replaced by other nutrients in terms of sorghum yield. This could be associated with the effects of N in the synthesis of chlorophyll, photosynthesis, and assimilated production. In comparison with the other treatments, the higher yield loss was recorded in the unfertilized plots and omitted N plots. These results were expected since that they could be the result of poor nutrient supply in the soil, which did not satisfy the N demand of the sorghum crop.

The results of this research are associated with Haile-Selassie et al. [44], the nonsignificant effect of phosphate fertilizer in fields having a higher inherent level of soil phosphorus. This might be the outcome of the excess application of phosphate fertilizer by farmers in the study area used to, which can lead to phosphorus build-up in the soil [45].

This outcome was consistent with Selassie's [46] findings, which elucidated nitrogen as the supreme yield limiting nutrient for maize productivity on Alfisol of Northwestern Ethiopia. The result also corroborated with Fageria [47], who explained nitrogen as one of the minerals that most severely restrict crop yields worldwide. This result is in line with other previous studies at Raya Kobo district (Getu et al. [34]). These findings are also in accordance with Abera and Kassa [48].

3.3. Nutrient Use Efficiency

3.3.1. Agronomic Efficiency of Nitrogen (AEN). The mean agronomic efficiency of N ranged between 11.8 and 19.7 kg grain kg^{-1}·N applied, depending on the quantity of fertilizer provided (Table 6). The highest mean agronomic efficiency (19.7 kg grain kg^{-1}·N) of N was attained from fully fertilized plots (NPKSZnB) with 34% increments over the lowest agronomic efficiency of N (P omitted plot) (Table 6). Similarly, the agronomic efficiency of N obtained from the recommended NP was higher than the agronomic efficiency recorded by omitting P, K, S, Zn, B, and both Zn and B plots. This increment might be due to the lower rate of N in the recommended NP rate. The result of this work also indicates that the agronomic efficiency of nitrogen was reduced in the order of omission of P > S > both Zn and B > Zn > B > K by 34%, 28%, 21%, 18%, 8%, 6%, and 5%, respectively, as compared with the fully fertilized plots. As demonstrated in the current work, the omission of one of these nutrients which is P greatly decreases the agronomic efficiency of nitrogen. Thus, the supply of P is essential to increase the AEN.

Table 7: Nutrient uptake of sorghum as influenced by nutrient omission.

Treatments	Total N uptake (kg ha^{-1})	Total P uptake (kg ha^{-1})
Control	79.4^{c}	6.7^{c}
PSZnB (−N)	83.2^{c}	7.8^{c}
NSZnB (−P)	136.9^{b}	14.0^{a}
NPSZnB(−K)	164.0^{ab}	12.9^{ab}
NPZnB (−S)	154.5^{ab}	13.8^{a}
NPSZn (−B)	174.8^{a}	12.2^{ab}
NPSB (−Zn)	164.5^{ab}	15.5^{a}
NPS (−ZnB)	138.4^{b}	14.3^{a}
RNP	139.7^{b}	10.7^{abc}
NPKSZnB	138.1^{b}	15.3^{a}
CV (%)	7.8	10.7

N.B: means in the columns that are denoted by the same letter do not differ substantially at $P \leq 0.05$.

The AEN recorded lies under an optimum range of agronomic efficiency of cereal grain per unit of nitrogen which is 10–30 kg grain kg^{-1} nitrogen described by Dobermann [22]. This author also stated that nitrogen use efficiency decreases with increasing N rate.

3.3.2. Agronomic Efficiency of phosphorus (AEP). The mean AEP ranged from −15.7–10.6 kg grain kg^{-1} P_2O_5 (Table 6). The maximum mean agronomic efficiencies of Phosphorus were obtained from the application of macro and micro nutrients, with agronomic efficiency increments over the N omitted plot by 97.6%. Similar findings on the agronomic efficiency of P for maize by Balemi et al. [49] confirmed the higher reduction of AEP in nitrogen omitted nitisols of Southwestern Ethiopia.

3.4. Nutrient Uptake

3.4.1. Nitrogen Uptake. The present results indicated a substantial ($P \leq 0.01$) difference in N uptake by nutrient omission (Table 7). Among the omitted nutrients, B omitted treatment had a higher total N uptake (174.8 kg·ha^{-1}) without significantly different from the application of NPS, NPSKZnB, and NPZnB. The lowest value of total N uptake was recorded with the control treatment (79.4 kg·ha^{-1}). This work implies that the application of macronutrients in combination with micronutrients improves N uptake. This result inlines with Weldegebriel et al. [21] reported that total nutrient uptake had a significant response to the nutrient application and low nutrient uptake was obtained from control, P and N alone. The same author stated that the application of NPKSZn fertilizer, considerably improved sorghum's ability to absorb nutrients. As a result, increasing nutrient uptake meant that there would be enough nutrients

Table 8: Pearson correlation coefficient between Sorghum's yield and yield components.

Variables	BY	GY	PH	SPAD
BY	1.00			
GY	0.96**	1.00		
PH	0.92**	0.89**	1.00	
SPAD	0.86**	0.91**	0.85**	1.00

Where ** = significant at $P \leq 0.01$, * = significant at $P \leq 0.05$. PH = plant height, GY = grain yield, BY = biomass yield and SPAD = SPAD reading.

available for sorghum to grow normally and provide a good yield. This outcome agrees with research by Choudhary et al. [50], who found that the application of micronutrients along with NPK fertilizers increases the concentration of nutrients in grain as well as stalk and so increases the total uptake of nutrients.

3.4.2. Phosphorus Uptake. A wide variation in P uptake among treatments ($P \leq 0.01$) was observed by the fertilizer treatments and control. Among the treatments, the highest overall P uptake (15.5 kg·ha^{-1}) was recorded in a plot treated by NPSB (Zn omitted) and the lowest total P uptake (6.7 kg·ha^{-1}) was recorded from unfertilized plots (Table 7). This study found that fertilization with N and P considerably boosted P absorption, indicating that these nutrients were more readily available or accessible in the soil [51]. This indicates applied nitrogen may give an increased phosphorus uptake by plants.

The present result conformed to that of Sharif et al. [52] in salt-affected soil. Sharif et al. [52] found that [52] plant P uptake by sorghum significantly increased over control. In addition, Haile Selassie et al. [44] confirmed N fertilizer gave considerably higher total P uptake. Fosu-Mensah and Mensah [51] also reported application of N and P considerably improved P grain absorption for maize due to their interaction with Haplic Lixisol.

3.5. Correlation of Yield and Yield Components of Sorghum. According to an investigation of the association between yield components and grain yield, all of the yield components are significantly linked with grain yield (Table 8). The present data showed that there was a very important ($P \leq 0.01$) positive and linear correlation among yield and yield components of sorghum (Table 8). In view of that, grain yield was desirable and significantly positive correlated with biomass yield ($r = 0.95^{**}$), plant height ($r = 0.89^{**}$) and SPAD reading ($r = 0.91^{**}$) at $P \leq 0.01$. A comparison of the correlation coefficient indicates that biomass gave a superior correlation coefficient ($r = 0.95^{**}$) to other yield components and plant height gave the lowest correlation coefficient ($r = 0.85^{**}$) than others. The biomass yield of sorghum was substantially linked with plant height and SPAD reading at $P \leq 0.01$. The positive correlation of all possible pairs of characteristics indicated the prospect of a correlated response, such that the other positively correlated characteristic would increase with the improvement of one characteristic. The outcomes of this investigation are consistent with Muhidin [53], who revealed that Grain yield showed highly [54] substantial and favorable connections with yield components mainly for leaf area index, plant height and biomass yield.

4. Conclusion and Recommendation

Considering the findings of the current investigation, it is conceivable to conclude that nitrogen is the most yield-limiting nutrient for sorghum production. The nitrogen and phosphorous uptake of sorghum were considerably improved by the combined application of phosphorus and nitrogen at the study site. The results showed that the mean agronomic efficiency of nitrogen and phosphorus is reduced when N and P are omitted.

In addition, these findings confirmed that omission of K, S, Zn, and B-containing fertilizer did not result in sorghum yield penalty, decreased agronomic N and P use efficiency and nitrogen and phosphorus nutrient uptake from the recommended NP. Therefore, the fertility status of the soil must be monitored and those nutrients would be yield-limiting in the future. Therefore, the target must be on only N containing fertilizers with phosphorus fertilizer (for soil fertility maintenance) to boost sorghum production and productivity.

Overall, the findings showed that omitting of N results in a sizable yield penalty followed by omitting P and the application of nutrients using site specific nutrient management technique should be used to increase sorghum production and profitability. As a result, to achieve the best sorghum yield for the study location, intensive research towards nitrogen fertilizer has to be done to determine the appropriate rates of nitrogen to meet the biological and economic optimum, while phosphorus could be used to keep fertility levels within a desirable range.

Data Availability

The rainfall, temperature, soil, and agronomic data used to support the findings of this study are included within the article.

Disclosure

This study was previously presented as thesis of Habtemariam Teshome under the supervision of Dr. Eyayu Molla and Dr. Tesfaye Feyisa and this work has been deposited at Bahir Dar University Institutional Repository System.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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