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Identifying Yield-Limiting Nutrients for Tef [Eragrostis Tef (Zucc.)Trotter] Across Landscape Positions in West Belesa District, Northeastern Ethiopia

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Abstract

Landscape position affects soil fertility through nutrient redistribution caused by erosion. In Ethiopia, soil fertility maps indicate deficiencies of essential nutrients, including Nitrogen (N), phosphorus (P), potassium (K), sulfur (S), Zinc (Zn), boron (B), and cupper (Cu). Therefore, a field experiment was conducted in West Belesa District to identify yield limiting nutrients for tef across landscape positions. The treatments were consisted of omitting K (All-k), S (All-S), Zn (All-Zn), B (All-B), and NPKSZnB (All blended), NPKSZnB (All straight), NPSZnB + K split, recommended NP, and control treatments in randomized complete block design with three replications. At the foot and mid slopes, the application of KSZnB nutrients did not significantly increase grain yields compared with the recommended NP nutrients. The highest grain yield were obtained from the full straight nutrient treatment, reaching 2310.7 kg ha^{-1} at the foot slope and 2112 kg ha^{-1} at the mid slope, but these yields were statistically similar to those obtained with NP alone. In contrast, fertilizer treatments significantly affected grain yield at the hill slope. The highest grain yield 1208 kg ha^{-1} was recorded from boron omitted treatment (All-B), while the control treatment consistently produced the lowest yields across all landscape positions. Overall, the findings are insufficient to draw definitive conclusions regarding nutrient limitations. Therefore, further multi-location and multi-season studies are recommended to identify the major yield limiting nutrients for tef production across different landscape positions.

1. INTRODUCTION

Landscape variability creates significant differences in soil fertility, both within and between farms due to variations in soil properties, topography, and moisture condition[1, 2].This variability is further aggravated by soil erosion, which removes nutrients from upper slopes and deposits them on lower slopes, resulting in uneven nutrient distribution[3]. Consequently, crop response to fertilizers varies across landscapes, and effective nutrient management requires proper identification of site-specific constraints and targeted fertilizer application to improve productivity and reduce yield gaps in smallholder systems[4, 5].

Tef [*Eragrostis tef (zucc.)Trotter*] is a major cereal crops in Ethiopia, cultivated on more than 3.1 million hectares and serving as a stable food for more than 70 million people [6]. It is mainly used to prepare *injera* and is valued for its high nutritional quality, including essential minerals rich in iron, calcium, protein contents, and its gluten-free nature[7, 8]. In addition to its food value, tef straw is an important livestock feed. Tef also has high economic importance, often fetching higher market prices than maize, making it an important cash crop for farmers[9]. Moreover, it is well adapted to a wide range of agro-ecological conditions, including marginal areas between sea level and 3,000 meters with varying annual rainfall of 300–800 mm and temperature between 10 and 27 ^{o}C [10].

Despite its importance, tef productivity is constrained by several biotic and abiotic factors. Of these, soil fertility reduction is one of the main causes of temporal and spatial variability[11]. Continuous use of limited fertilizers like Urea and DAP, along with residue removal, has further depleted soil nutrients [12].National soil fertility assessments map have shown widespread deficiencies of essential nutrients such as N, P, K, S, Zn, B and Cu [13]. In Ethiopia, although the new formulated fertilizers were available on the fertilizer market, many researchers argued that N and P are the only yield limiting nutrients in cereal crops. Therefore, the objective of this study was to identify the major yield limiting nutrients for tef production across different landscapes.

2. MATERIAL AND METHODS

2.1. Description of the study area

The experiment took place during the main cropping season of 2022/2023 in west Belesa District, located within the Central Gondar Administrative Zone of Amhara Regional State, Ethiopia. The study area is situated between 12º 13' 11" to 12º 41' 4" North latitude, and 37º 37' 9" to 38º 3' 8" East longitude (Fig. 1). The elevation of the area ranges from 1100 to 2350 meters above sea level. According to Ahmed et al.[14], the agro-ecological Zones are predominantly lowland (59.8%), followed by midland (38.7%) and highland (1.5%). During experimental year, the area received an average annual rainfall of 982 mm, with minimum and maximum temperatures of 9.5°C and 35°C, respectively (Ethiopian Meteorological service Agency (EMSA) (Fig. 2). The area experiences a single rainy season that begins in June and ends in September. The local farming system is a combination of crop and livestock production. The landscape was divided into different zones based on Catena sequences which include foot slope, mid slope, and hill slope. The slope percentages are categorized as 0–5%, 5–15%, and greater than 15%, respectively[14].

2.2. Treatments and Experiment Design

The experiment was consisted a total of nine treatments, including NPKSZnB-blended, NPKSZnB (Straight Fertilizer), NPSBZn + K Split (compound form/OCP all), NPKZnB (All-S), NPKSB (All-Zn), NPKSZn (All-B), NPSZnB (All-K), NP, and control (without nutrient). The Fertilizer source Urea, DAP, KCl, NPS, Solubar, Zinc Sulphate Monohydrate was used as nutrient sources for Nitrogen, Phosphorus, Potassium, Sulphur, Boron and Zinc with the rate of 60 kg ha^{-1} N,38 kg ha^{-1} P_2O_5, 60 kg ha^{-1} KCl with the rate of 60 kg ha^{-1} N, 38 kg $ha^{-1}P_2O_5$, 60 kg ha^{-1} KCl, 7.4 kg ha^{-1} NPS, 0.75 kg ha^{-1} of solubar and 0.25 kg ha^{-1} of Zinc Sulfate Monohydrate, respectively (Table 1).The treatments were arranged in randomized complete block design (RCBD) with three replications using Boset tef variety as a test crop. Each plot had a gross size of $12m^2$ (4m x 3m) and a net harvestable area of 9.6 $m^{2,}$ with 20cm row spacing. All nutrients were applied at sowing, except in the split application treatment where half of N and K were applied at sowing and the remaining half was side dressed 35–40 days after sowing. The treatment setups are shown as in Table 1.

Table 1
Treatments and their nutrient compositions

Treatments		Nutrient rates applied in hectare (kg ha^{-1})					
	Descriptions	N	P	K	S	Zn	B
1	NPKSZnB(All-blended)	60	38	60	7.4	0.75	0.25
2	NPKZnB (All-S)	60	38	60	0	0.75	0.25
3	NPKSB (All-Zn)	60	38	60	7.4	0	0.25
4	NPKSZn (All-B)	60	38	60	7.4	0.75	0
5	NPSZnB (All-K)	60	38	0	7.4	0.75	0.35
6	Rec.NP	60	38	0	0	0	0
7	NPKSZnB(All-Straight)	60	38	60	7.4	0.75	0.25
8	NPSZnB + K Split	60	38	60	7.4	0.75	0.25
9	Control	0	0	0	0	0	0

2.3. Land preparation and Experimental procedures

The experimental field was prepared following the conventional tillage practices of the area. The sites were plowed 2–3 times using ox-drawn plowing, then harrowed and manually leveled. The field was divided into blocks and plots, with 1m spacing between blocks and 0.75m between plots, and rows spaced at 20cm.The Boset tef variety was used as the test crop. The Full doses of all nutrients were applied at sowing, while half of N and K in treatment 8 (T8) were applied at sowing and the remaining half was top-dressed 35–45 days after sowing, All plots were managed uniformly with timely weeding and other agronomic practices.

2.4. Soil Sampling and Analysis

Composite soil samples at (0-20cm depth) were collected before planting from five randomly selected spots per site using auger in a diagonal pattern. The samples were mixed, and a 1 kg representative sample was prepared, labeled, and analyzed at Debre Birhan Agricultural Research Center soil laboratory. Samples were air-dried, crushed, and sieved with 2mm.

Soil pH was measured in a 1:2.5 soil water suspension rations according to Taye et al. [15]). Total nitrogen (TN) was determined using the Kjeldahl method, and available phosphorus was determined by using Olsen's calorimetric method as described by Olsen et al.[16]. The wet digestion method was used to determine the OC content of the soil [17]. A spectrophotometer was used to measure soil available Sulphur. Available Zn was determined using Atomic Absorption spectrophotometer (AAS) after extraction of samples by DTPA solution and boron was determined by using hot-water extraction method following the procedure mentioned by Estefan et al.[18].

2.5. Data collection and Analysis

Key agronomic and yield data were collected following standard procedures. Data collection comprised plant height; panicle length; biomass, and grain yields. Plant height and panicle length were measured in centimeter from ten randomly selected plants in the central rows and averaged. Biomass yield (kg ha^{-1}) was determined from plants harvested from the net harvestable plots at ground level, sun-dried, and weighed. Grain yield (kg ha^{-1}) was measured after threshing, adjusted to 12.5% moisture content, and converted to grain kg ha^{-1}.

Subsequently, the normality and homogeneity of variance for all dataset were assessed using Shapiro and Leven's tests, respectively, in R software program (Version 4.2.2) [19].The effect of independent variables (treatments) on the dependent variables (yield and yield components) was statistically tested. Analysis of variance (ANOVA) was carried out to assess the difference among treatments using the statistical Analysis system (SAS) Version 9.3 [20].The least significant (LSD) was used for mean separation at 5% probability level.

3. RESULT AND DISCUSSION

3.1. Soil physicochemical properties

The soil analysis result indicated slight variability in soil properties (pH, total nitrogen, available phosphorus, organic carbon, sulfur, boron, and zinc) across foot, mid, and hill slope positions (Table 2). Soil pH ranged from 7.8 at the hill slope to 8.6 at the foot slope, which falls within the range of moderately to strongly alkaline soils [21]. The relatively higher pH values at the foot and mid slopes could be attributed to the accumulation of basic cations (Ca^{2+},Mg^{2+},K^{+}, and Na^{+}) transported from upper slopes through runoff, while the lower pH at the hill slope may result from leaching and erosion processes. These finding are consistent with reports by Balasundram et al. [2, 3], who reported the influence of topography on soil nutrient distribution.

Total nitrogen (TN) content was uniformly low (0.10–0.15%) across all slope positions, as described by [22]. The slightly higher TN observed at the foot and mid slopes may be associated with the deposition of organic materials and fine particles. However, the overall low nitrogen content suggests the need for nitrogen supplementation through fertilizers or organic inputs. Available phosphorus (P) ranged from 2.3 to 4.93 ppm and was categorized as low [16]. Interestingly, the hill slope recorded relatively higher P levels, possibly due to reduced phosphorus fixation under comparatively lower pH or lower plant uptake. In contrast, lower P levels at the foot and mid slopes may be due to fixation by calcium under alkaline conditions.

Organic carbon (OC) content varied from 0.66% at the hill slope to 1.06% at the foot slope, which is considered low according to [21].The higher OC at the foot slope reflects the accumulation of organic matter transported from upper slopes, while the lower OC at the hill slope is likely due to erosion and reduced biomass return. Sulfur (S) content varied from 1.13 to 3.2 ppm and was generally low [23], with relatively higher values at the foot slope indicating deposition effects. Similarly, boron (B) content ranged from 0.3 to 0.5 ppm and was low across all slope positions [24], though slightly higher at the foot slope. Zinc (Zn) content ranged from 0.60 to 0.71 ppm and was classified as medium [25], with minor variations among slope positions.

Table 2
Soil physic-chemical properties of experimental sites across landscapes

District	Landscape position	Description	pH (H_2O)	TN (%)	Ava.P (ppm)	OC (%)	S (ppm)	B (ppm)	Zn (ppm)
West Belesa	Foot	One site	8.6	0.15	2.3	1.06	3.2	0.5	0.65
	Mid	Two site	8.3	0.15	2.42	1.05	1.13	0.3	0.71
	Hill	One site	7.8	0.1	4.93	0.66	2.63	0.4	0.6
	Ratings		Moderate-strongly alkaline	low	low	low	low	low	medium

Note: pH= power of hydrogen concentration; TN= total nitrogen; Ava.P= Available phosphorous; OC % = organic carbon; S= sulfur; B= boron; Zn= zinc

3.2. Effect of Treatments on yield and yield components of tef across landscapes

Plant height and Panicle length

The result showed that fertilizer treatments significantly influenced plant height (PH) and panicle length (PL) across all landscape positions (foot, mid, and hill slopes) (Table 3). At the foot slope, all fertilized treatments resulted in statistically similar plant height (90.8-96.5cm), with the highest value recorded from NPKZnB (All-S) and NP treatments (96.5cm).Panicle length was also improved, with the maximum (37.2cm) obtained from NPKZnB (All-S). The relatively better performance at the foot slope can be attributed to higher soil fertility due to nutrient accumulation can enhances from upper slopes which crop response to applied fertilizers. Similar trends were reported by Tesfaye et al.[26], who reported that lower slope positions often show better crop performance due to depositional effects.

In the mid slope, significant differences were observed among treatments. The highest PH (87.6cm) was obtained from NPKSZnB (Straight), while the lowest (64.7cm) was recorded in the control. Panicle length also followed a similar pattern, with fertilized treatments (32.0-32.6cm) outperforming the control (27.2cm).At the hill slope, although most fertilized treatments showed comparable PH (84.9-88.4cm) and PL (31.7-34.5cm), the control treatment again recorded significantly lower values (PH: 51.7 cm and PL: 21.3cm) (Table 3).The slightly reduced performance of fertilized plots compared to the foot slope may be due to lower inherent soil fertility, higher erosion, and reduced moisture retention at upper slopes. This is consistent with reports by Subhatu et al.[27], who emphasized that mid slopes are transitional zones where both erosion and deposition occur, affecting soil nutrient availability.

In general, the control treatment consistently recorded the lowest values of plant height (76.0, 64.7, and 51.7cm) and panicle length (32.2, 27.2, and 21.3cm) at foot, mid, and hill slopes, respectively), indicated that N and P are the most growth limiting nutrient, as plant height and panicle length increased when nutrient applied. Since, omitting of sulfur, potassium, Zinc, and boron had no significant effect on yield parameters of tef as compared with NP nutrient sources across landscapes. These results lined with Esubalew, T., and

Sebnie, W.[28], who reported that potassium, zinc, and boron is not quiet growth-limiting nutrients' for Sorghum in Wag-Lasta, Northern, Amhara region. Similarly, Alemayehu et al.[29], who reported that N and P are the most plant height and growth limiting nutrients for tef crops in Northwest Amhara. The other studies by Bazie et al.[30] and Agegnehu et al.[31], who indicated that wheat and tef yield and yield attributes were significantly limited by N and P nutrients. Getinet, H. [32], also reported that maximum yield and yield components reduction on maize crop was observed from N and P omissions.

Table 3. Effect of nutrient Omissions on yield components of tef across landscapes

No.	Treatment Descriptions	Landscape positions					
		Foot slope		Mid slope		Hill slope	
		PH	PL	PH	PL	PH	PL
1	All-1	90.8^{a}	35.9^{ab}	87.1^{a}	32.5^{a}	86.8^{a}	32.2^{a}
2	All-S	96.5^{a}	37.2^{a}	84.7^{ab}	32.3^{a}	85.3^{a}	34.1^{a}
3	All-Zn	94.4^{a}	34.9^{ab}	85.5^{ab}	32^{ab}	87.4^{a}	34^{a}
4	All-B	94.7^{a}	36.1^{ab}	85.7^{ab}	32.5^{a}	85.6^{a}	32.5^{a}
5	All-k	93.4^{a}	34.6^{b}	86.5^{ab}	32.6^{a}	88.4^{a}	34.5^{a}
6	NP	96.5^{a}	35.7^{ab}	83.2^{b}	30.9^{b}	84.93^{a}	31.7^{a}
7	All-2	94.6^{a}	36.0^{ab}	87.6^{a}	32.5^{a}	86.5^{a}	32.6^{a}
8	All-3	92.7^{a}	35.4^{ab}	85.6^{ab}	32.1^{ab}	87.9^{a}	33.6^{a}
9	Control	76.0^{b}	32.2^{c}	64.7^{c}	27.2^{c}	51.7^{b}	21.3^{b}
	Sign.	**	*	**	**	**	**
	LSD (0.05)	6.58	2.36	3.58	1.34	7.25	3.82
	CV (%)	4.12	3.86	3.69	3.66	5.06	6.94

Note: All-1=NPKSZnB-blended; All-2=NPKSZnB (Straight) or individually applied; All-3= NPSZnB-compound +K split; PH=plant height; PL= panicle length; NP= nitrogen and phosphorus; Sign. =significance at 5% level; LSD= least significance difference; CV=coefficient of variation; **= significant at 1% probability level,*=significant at 5% significance level; Mean followed by the same letter in the column are not significant at 5% significant level.

Biomass

The analysis of variance showed that biomass yield was significantly ($p < 0.05$) affected by fertilizer treatments across all landscape positions (Table 4).At the foot slope, biomass yield ranged from 2356 kg ha^{-1} (control) to 6010.3 kg ha^{-1} (NPKSZnB, straight). The treatment NPKSZnB (straight) produced the highest

biomass and was statistically superior to the control, but not significantly different from NP (5342 kg ha^{-1}), since both fall within the same statistical group. Most blended treatments (5408-5652.7 kg ha^{-1}) were also statistically similar to NP, indicating no significant advantage over NP under relatively fertilize foot slope conditions. However, all fertilized treatments were significantly higher than the control (2356 kg ha^{-1}).This suggests that while fertilization greatly improves biomass over the control, the addition of micronutrients did not create a strong statistical difference compared to NP at the foot slope.

At the mid slope, biomass varied from 1778 kg ha^{-1} (control) to 5498.3 kg ha^{-1} (NPKSZnB, Straight). The highest biomass (5498.3 kg ha^{-1}) was significantly greater than NP (4205.8 kg ha^{-1}), as they belong to different statistical groups (Table 4). Treatments such as NPKZnB (All-K) 4878.5 kg ha^{-1} showed intermediate performance and were not significantly different from NP, but superior to the control. The control treatment was significantly lower than all fertilized treatments, confirming strong nutrient limitation. Overall, some blended fertilizers provided a statistical advantage over NP, particularly the fully balanced treatment applied in straight form.

At the hill slope, biomass ranged from 461.7 kg ha^{-1} (control) to 3798.7 kg ha^{-1} (NPKSZn, All-B).The highest biomass in (All-B) 3798.7 kg ha^{-1} was significantly higher than NP (2149.7 kg ha^{-1}). Similarly, Treatments NPSZnB + K split (3104 kg ha^{-1}) also showed significant improvement over NP. Most blended treatments (2614.3-2918.3 kg ha^{-1}) were statistically higher than NP or at least in better groups. The greater statistical differences at the hill slope indicate that crops responded more strongly to added nutrients under poorer soil fertility conditions. This inconsistent result may be due to tef population uniformity problem across plots in the hill slope.

Therefore, in all landscapes especially in foot and mid slope classes the application of different sources of fertilizer was not significantly differ from NP nutrient. Generally, Nitrogen and phosphorus are the most important nutrients for increasing the biomass yield of tef which is supported by[33, 34], Who reported as new fertilizers including potassium, zinc, and boron are not still yield-limiting for maize, wheat and tef crops in the Northwestern highlands of Ethiopia.

Grain yield

The analysis of variance (ANOVA) result showed that the yield was significantly affected by different nutrient fertilizer across all landscape positions (Table 4). At the foot slope, the highest grain yield (2310.7 kg ha^{-1}) was obtained from NPKSZnB (straight), followed by NPSZnB (All-K) (2179 kg ha^{-1}) an NPKSZn (All-B) (2142.3 kg ha^{-1}), while the lowest (820.3 kg ha^{-1}) was recorded from the control. However, most fertilized treatments, including NP (2016 kg ha^{-1}) showed no significant difference among them. The maximum yield increased by 181.7% compared to the control, indicating that NP alone was sufficient under this condition.

At the mid slope, grain yield ranged from 844.8 kg ha^{-1} (control) to 2112 kg ha^{-1} under (NPKSZnB, Straight) treatment, showing a 150% yield advantage over the control. The highest treatment also exceeded NP by 299.5 kg ha^{-1}. Treatments such as NPKSZn (All-B) and NPSZnB (All-K) performed similarly with NP treatment. This indicates a moderate response of soil due to intermediate fertility status. At the hill slope,

grain yield was lowest due to poor soil fertility and erosion effects. The highest yield (1208.3 kg ha^{-1}) was obtained from NPKSZn (All-B), while the lowest 168.3 kg ha^{-1} was recorded under the control. This represents a 618% increase over the control. NP treatment produced 774.3 kg ha^{-1}, which was significantly lower than the best treatment. Unlike the other positions treatments showed clear differences, indicating the importance of balanced fertilization under degraded conditions.

Overall, grain yield varied across landscape positions, with the highest yield at the foot slope, followed by the mid and hill slope (foot slope > mid slope > hill slope) (Table 4).Across landscapes, omitting sulfur, potassium, Zinc, and boron did not significantly reduce yield particularly at the foot and mid slopes. This suggests that NP fertilizer alone was sufficient to maximize tef production in the study area.

This finding agrees with Amare et al. [35] and Alemayehu et al.[29], who reported that potassium, sulfur, Zinc, and boron are not yield limiting nutrients for maize, wheat, and tef in the Northwest of Ethiopia. Similarly, Amede et al.[36] Indicated that NP application is more important than additional macro and micronutrients for improving wheat yield. The study conducted by Kolawol et al. [37] and Rawal et al. [38] also indicated that N and P are the most yield limiting nutrients for cereal production. In addition, Agegnehu et al. [34] and Bazie et al.[30], conducted that various wheat growing areas in Ethiopia do not require K, S, Zn, and B nutrients to achieve high yields. However, the result contrast with Chala et al.[39] and Gessesew et al. [40] who reported that applying higher rates of N, P, S, Zn, and B nutrients enhance crop yield.

Table 4. Effect of nutrient omission on Grain yield and biomass of tef across landscapes

No.	Treatment Descriptions	Landscape positions					
		Foot slope		Mid slope		Hill slope	
		GY	BM	GY	BM	GY	BM
1	All-1	2057.3^{a}	5408^{ab}	1893.5^{abc}	4198.8^{b}	828^{ef}	2918.3^{bc}
2	All-S	2054^{a}	5146^{b}	1623^{c}	4326.5^{b}	927de	2351^{cd}
3	All-Zn	2111^{a}	5593.7^{ab}	1838.5^{bc}	4514.3^{b}	1073^{bc}	2684^{bcd}
4	All-B	2142.3^{a}	5652.7^{ab}	2046.8^{ab}	4371.5^{b}	1208.3^{a}	3798.7^{a}
5	All-k	2179^{a}	5422^{ab}	1931^{ab}	4878.5^{ab}	1013^{cd}	2614.3^{bcd}
6	NP	2016^{a}	5342^{ab}	1812.5^{bc}	4205.8^{b}	774.3^{f}	2149.7^{d}
7	All-2	2310.7^{a}	6010.3^{a}	2112^{a}	5498.3^{a}	937.7^{de}	2774.3^{bcd}
8	All-3	2005.3^{a}	5316^{ab}	1844.5^{abc}	4466.2^{b}	1146^{ab}	3104^{ab}
9	Control	820.3^{b}	2356^{c}	844.8^{d}	1778^{c}	168.3^{g}	461.7^{e}
	Sign.	**	**	**	**	**	**
	LSD (0.05)	314.73	794.17	272.51	808.14	116.14	700.76
	CV (%)	9.24	8.92	13.02	16.33	7.478	15.94

Where; All-1=NPKSZnB-blended; All-2=NPKSZnB (Straight) or individually applied; All-3= NPSZnB-compound +K split; GY= grain yield kg ha^{-1}; BM=biomass in kg ha^{-1}; CV%= Coefficient of variation; LSD= least significant difference; **= significant at 1% probability level; Mean followed by the same letter in the column are not significant at 5% significant level.

4. CONCLUSION AND RECOMMENDATIONS

In general, omitting of potassium, sulfur, Zinc, and boron nutrients did not show significant yield penalty as compared to the NP nutrients, especially in the foot and mid landscapes in the study area. This indicates that nitrogen and phosphorous are the most tef yield limiting nutrients in the study areas. However, in hill slope the result was not consistent as foot and mid slope. This may be due removal of fertile soil through erosion and problem of population uniformity within plots due to the presence of smaller gravels in hill slopes. Based on these results it is difficult to draw conclusion. Therefore, we recommended conducting further research to confirm most yield limiting nutrients in all landscapes.

Declarations

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Author contributions

Tesfaye Feyisa, Hailu Kindie: Conceptualization of the proposal; Habtamu Getnet performed the experiment, data collection, analysis, and drafted the manuscript; Ayalew Addise, Baye Ayalew, Tarekegn Yibabie, Firnus Haile, Zerfu Bazie, Melkamu Adane and Tamrat Worku performed the experiment and data collection. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The raw data supporting the conclusions of this article will be given to the corresponding authors without precondition upon request.

Ethics approval and consent to participate

Not applicable.

Consent for publication

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Sources of the plants used in this study

Not applicable.

Competing Interests

The authors declare no competing interests.

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Figures

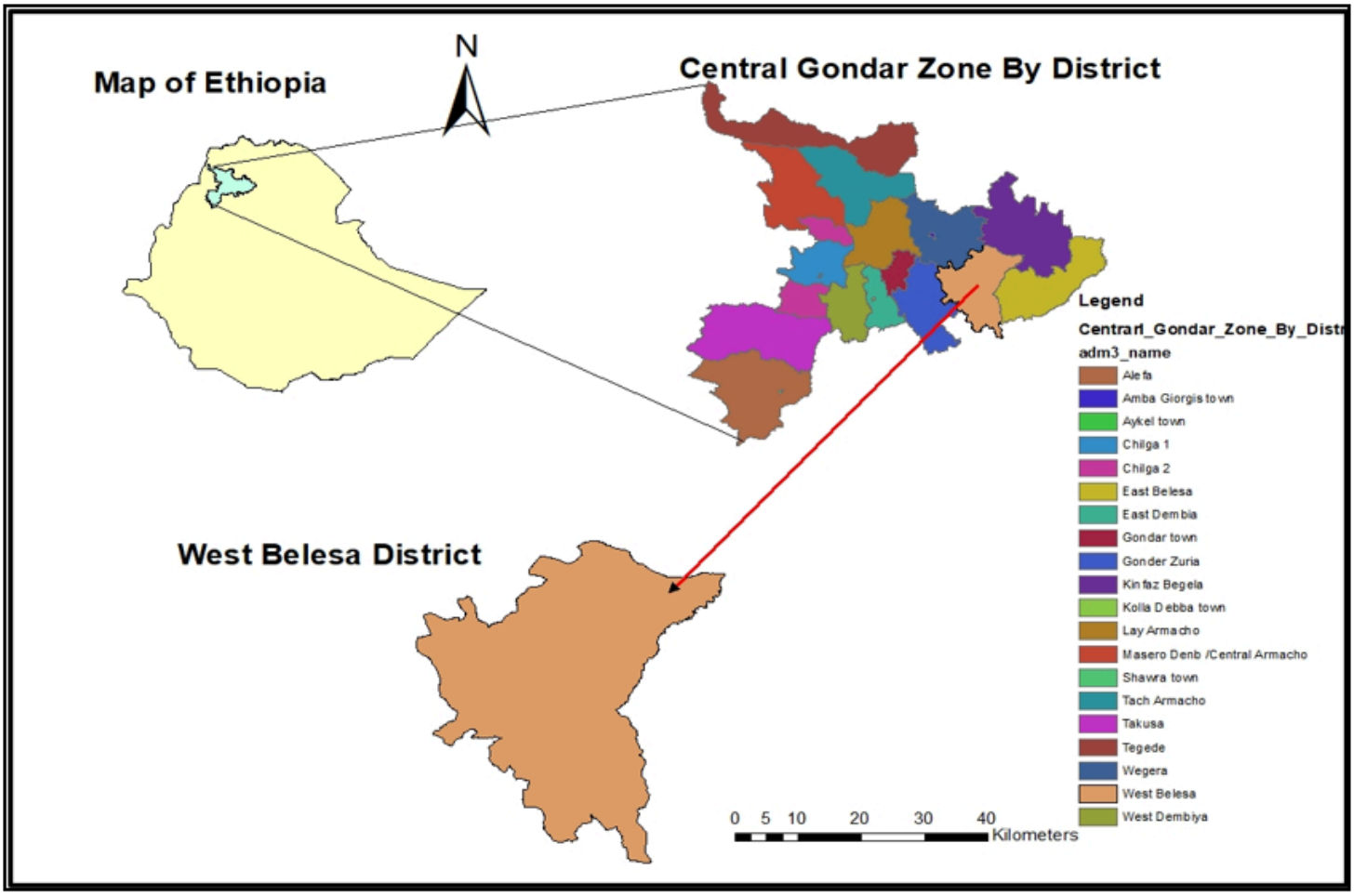


Figure 1

Map of study area

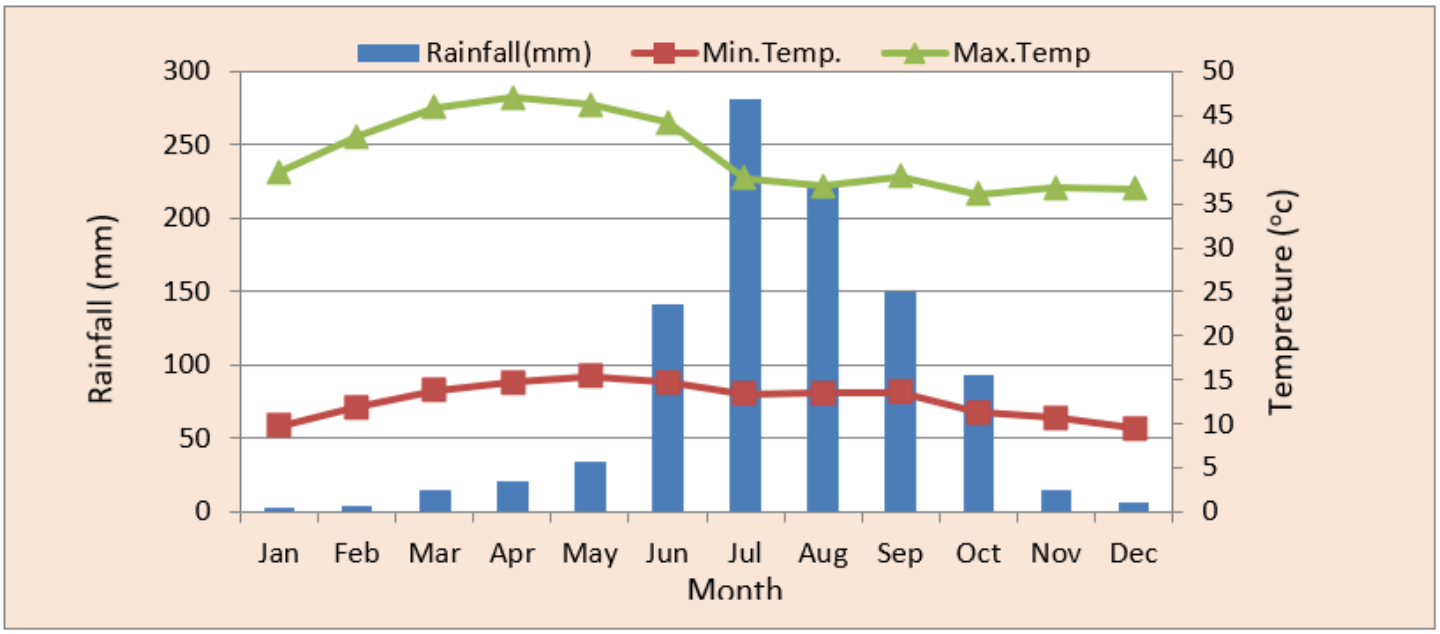


Figure 2

The means annual rainfall, minimum and maximum temperature of the study area