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Identifying yield limiting nutrient(s) for better teff (Eragrostis tef) productivity in Vertisols of Central, Ethiopia

Teshome Bekele

teshbekbej@gmail.com

Ethiopian Institute of Agricultural Research

Tesfaye Yaekob

Ethiopian Institute of Agricultural Research

Bethel Nekir

Ethiopian Institute of Agricultural Research

Yitegasu Nurga

Ethiopian Institute of Agricultural Research

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Abstract

*Food crop productivity is still low because of the decline of soil fertility, particularly in Central Ethiopia. Fine-tuning the source and rate of nutrients is required to solve soil fertility problems .Teff (*Eragrostis tef*) is a staple cereal in central Ethiopia, yet its productivity on Vertisol soils remains limited by nutrient deficiencies and improper use of nutrient management constraints. Therefore, this study was initiated to investigate the need to apply selected nutrients to tef in vertisols.The study evaluated the effects of macro and micronutrient omission on teff growth, biomass, grain yield, and harvest index across two cropping seasons at multiple sites in central Ethiopia. A randomized complete block design with ten nutrient treatments including a full NPKSZnB package, nutrient omission scenarios, and locally recommended rates was used to identify yield-limiting nutrients and quantify teff response. The available data were collected and subjected to ANOVA using SAS 9.3 software. The LSD test was used to separate means at 5% level of significance .Initial Soil analyses of selected site indicated slightly acidic to neutral pH, moderate to high cation exchange capacity, variable organic carbon, and uneven phosphorus availability, reflecting moderate soil fertility limitations. Results showed nitrogen and phosphorus as the most critical constraints, with their omission causing substantial reductions in plant height, panicle length, biomass, grain yield, and harvest index. Full nutrient application consistently produced the highest growth and yield, while the omission of secondary nutrients (sulfur, zinc and boron) had no statistically significant effect on teff yield or its yield components. This study emphasizes the significant contribution of key nutrients, notably nitrogen and phosphorus, to increased teff productivity on Vertisols in central Ethiopia. These findings provide evidence to refine fertilizer recommendations and implement integrated nutrient management strategies, supporting more productive, resilient, and food secure teff based cropping systems in Central Ethiopia.*

1 Background

Achieving food security is the main challenge for the agricultural sector in Ethiopia [1]. It is possible to address the food security and sustainability challenges that lie ahead, but it will demand significant shifts in how nutrients and water are managed[2]. Crop productivity has not been improved due to the decline in soil fertility [3–5]. Adding synthetic fertilizer is one of the major options to enhance crop productivity. Teff (Eragrostis tef) is a major staple cereal in Ethiopia, contributing to national food security, rural income generation, and cultural diets [6]. The crop is well adapted to diverse agro-ecological conditions, including marginal environments where other cereals perform poorly [7]. However, productivity remains low, with yields far below potential level, largely due to improper fertilizers application and soil fertility depletion at different agro ecology of Ethiopia region [8, 9].

In the central highlands of Ethiopia, Vertisols are among the dominant soils used for teff cultivation [10]. These soils are expand when wet and shrink when dry, Very slow infiltration rate,have high clay content and pronounced shrink swell behavior, and Easily waterlogged, especially during rainy season which strongly affect nutrient dynamics and crop growth [11, 12]. Although they contain substantial total nutrient reserves, physicochemical constraints frequently limit nutrient availability, reducing uptake and utilization efficiency.Nitrogen (N) and phosphorus (P) are the primary limiting nutrients for cereal production on Ethiopian soils, including Vertisols [9, 8].

Deficiency of nitrogen results in chlorosis, reduced vegetative growth, and low biomass accumulation, whereas phosphorus deficiency leads to poor root development, delayed maturity, and reduced grain yield [13]. Deficiencies of secondary and micronutrients, such as sulfur (S), zinc (Zn), and boron (B), may further constrain yields. Addressing these limitations requires systematic approaches such as nutrient omission trials to identify yield-limiting nutrients and quantify crop responses. In central Ethiopia, location-specific information on teff yield responses to applied nutrients is limited, constraining the development of balanced, site-specific fertilizer recommendations. This study aimed to identify yield-limiting nutrients and quantify the productivity response of teff on Vertisols of central Ethiopia

2 Materials and Methods

2.1 Study Area and Experimental Locations

On-farm plant nutrient omission experiments were conducted over two consecutive main cropping seasons (2022/23 and 2023/24) in central Ethiopia, covering the South West Shoa Zone, Gurage Zone, and Kebena Special Woreda. A total of Sixteen experimental sites were selected across the districts of Goro, Kebena Special Woreda, Abeshige and Ezha to capture a representative range of agro-ecological conditions. Site selection was guided by teff production potential, with the aim of including locations that vary in soil type, fertility status, and climatic conditions, thereby ensuring that the experimental results reflect the diversity of growing environments typical of the region.



2.2 Experimental Design

The core set of treatments was harmonized with nutrient omission design. Treatments were arranged in a completely randomized block design with three replications in all study sites to control for variability within each site (Table 1). Each experimental site was divided into three blocks, and within each block, the treatments were randomly assigned to individual plots. A total of ten treatments were included, representing different nutrient omission or inclusion scenarios, along with a control with no nutrient application. Each treatment was replicated three times per site, and all plots measured 3 m × 4 m. To minimize interference between treatments, plots were separated by 1 m, while blocks were separated by 1.5 m wide buffer zones.

Table 1
Description of treatments in the nutrient omission trials conducted in study areas.

No	Treatments	Treatment Description
1	Full NPKSZnB	All nutrients applied (nitrogen, phosphorus, potassium, sulfur, zinc, and boron)
2	(All – B)	Applied all nutrients except boron
3	(All – Zn)	Applied all nutrients except zinc
4	(All – S)	Applied all nutrients except sulfur
5	(All – K)	Applied all nutrients except potassium
6	(All – P)	Applied all l nutrients except phosphorus
7	(All – N)	Applied all l nutrients except nitrogen
8	(RNP)	A standard recommended nutrient package based on local agricultural guidelines
9	Control	No nutrient application at all
10	RNP + S_2	A standard recommended nutrient package and additional sulfur

2.3 Fertilizer sources

Urea, triple superphosphate (TSP), potassium chloride (KCl), and borax were used as sources of nitrogen (N), phosphorus (P), potassium (K), and boron (B), respectively, while zinc sulfate ($ZnSO_4 \cdot 7H_2O$) served as a source of both zinc (Zn) and sulfur (S). All fertilizers, except urea, were applied as a single band at planting. Urea was applied in split doses, with the second application of nitrogen applied one month after crop emergence to meet the crop's nutrient requirements during early growth stages.

2.4 Nutrient Application Rates

Nutrient application rates were carefully determined and applied uniformly across all trial sites to meet the crop's nutrient requirements. The rates for each fertilizer source were organized systematically (Table 2). This standardized approach ensured consistent nutrient supply and allowed for accurate comparison of treatment effects across the experimental locations.

Table 2
Treatment arrangements and nutrient application rates

Trt No	Treatment description	Urea (kg ha^{-1})	TSP (kg ha^{-1})	KCl (Mop) (kg ha^{-1})	$MgSO_4$ (kg ha^{-1})	ZnEDTA (kg ha^{-1})	Borax (kg ha^{-1})
1	Full NPKSZnB	54	124	100	81.4	33.33	9.17
2	(All – B)	54	124	100	81.4	33.33	0
3	(All – Zn)	54	124	100	81.4	0	9.17
4	(All – S)	54	124	100	0	33.33	9.17
5	(All – K)	54	124	0	81.4	33.33	9.17
6	(All – P)	54	0	100	81.4	33.33	9.17
7	(All – N)	0	124	100	81.4	33.33	9.17
8	(RNP)	54	124	0	0	0	0
9	No fertilizer	0	0	0	0	0	0
10	RNP + S_2	54	124	0	232.6	0	0

2.5 Agronomic Practices

Previous land preparation practices and Previous Crop residues management history were documented to minimize confounding effects on nutrient availability. Agronomic management was conducted according to recommended practices for teff cultivation to ensure optimal establishment and growth under the experimental conditions. Experimental fields were prepared through plowing and harrowing to obtain a uniform, fine seedbed suitable for precise sowing. Seeds of teff (*Eragrostis tef*) were sown at the recommended rate of **15** kg ha^{-1}, with row spacing of 20 cm to ensure uniform plant density and adequate aeration. Sowing was performed at the onset of the main rainy season to provide sufficient soil moisture for germination. Weed management was implemented through regular hand weeding to maintain weed-free plots during critical growth stages. Pest and disease monitoring was conducted throughout the crop cycle, and standard interventions were applied uniformly across all treatments.

2.6 Data Collection

2.6.1. Soil sampling

Before starting the experiment, soil samples were collected to understand the initial condition of the study sites. At each selected trial locations, a composite soil sample was taken from the top 0–20 cm layer, which is the main root zone for most crops. To make each sample representative, several subsamples were collected randomly across each plot in a zigzag pattern and then mixed thoroughly to form one composite sample per site. The samples were air-dried, gently crushed, and sieved using a 2 mm mesh before laboratory analysis.

2.5.2. Biological data

Data on teff growth, development, and yield were collected systematically from each experimental plot throughout the cropping seasons. Observations included key agronomic traits such as plant height and panicle length was recorded from ten representative plants per plot. Biomass yield was determined by harvesting aboveground plant material from a central area of 2 m × 2 m within each plot to avoid border effects .Grain yield was measured from the same central area after threshing and adjusting to 12.5% moisture content. Harvest Index (%) was determined as a ratio of grain yield to above-ground biological yield on a dry weight basis in percentage as described in the following formula.

$$HI\,(\%) = \left(\frac{\text{Grain yeild}}{\text{Above ground biomass yeild}}\right) \text{*100}$$

2.6 Soil analysis

All collected soil samples were air-dried, gently crushed, and sieved through a 2 mm mesh before analysis. Laboratory analyses focused on surface soil (0–20 cm depth) to evaluate key Chemical properties, including soil pH (H_2O), cation exchange capacity (CEC), available phosphorus (P), organic carbon (OC), and total nitrogen (TN). Soil pH was measured in a 1:2.5 soil-to-water suspension using a calibrated pH meter [19]. Organic carbon was determined using the Walkley Black wet oxidation method [14]. While total nitrogen was analyzed using the Kjeldahl digestion method [15]. Available phosphorus was extracted following the Olsen method [16] and CEC was determined using the ammonium acetate saturation method at pH 7. [17]

2.7 Statistical Analysis

The experimental data were analyzed using analysis of variance (ANOVA) in SAS software [20]. Treatment effects were considered significant at a 5% probability level, and mean differences were compared using the least significant difference (LSD) test. In addition, coefficients of variation (CV) were calculated for each parameter to evaluate the consistency and precision of the results. This approach provided a reliable framework for interpreting the effects of treatments and the variability within the data.

3 Results

3.1 Description of soil properties

The initial soil chemical properties of the selected sites indicated slightly acidic to neutral conditions (Table 3). The soils showed moderate to high nutrient-holding capacity, indicating effective retention of essential cations and sustained nutrient supply, largely due to cation exchange capacity associated with organic matter [21, 22]. Available phosphorus varied among sites, with some areas showing sufficient levels to meet crop demand, while others likely require additional phosphorus supplementation to avoid limitations in plant growth and yield, as phosphorus is often fixed in unavailable forms in soils despite total P content [23, 24]. Total nitrogen of the selected sites was generally low, indicating a potential yield limitation, while organic carbon was low to moderate, reflecting variable soil organic matter that affects nutrient retention and soil fertility [24].

Table 3
Initial Soil Chemical Properties of Experimental site

List of kebele	Parameters				
	pH	CEC (cmol(+)/kg)	Av. P(mg/kg)	TN(%)	SOC (%)
Dekishimola	6.8	33.1	14.6	0.09	0.68
Mamade	6.5	30.6	13.87	0.087	0.54
Adamiwodesa	6.54	29.1	19	0.14	0.98
Finchir	6.3	37.13	26	0.18	0.75
Darcha	6	30.41	14	0.017	0.23
Lache	6.7	27.98	17.43	0.089	0.13
Chanchote	6.51	31.98	11.65	0.076	0.43
Kolakabada	6.98	39.25	21.2	0.023	0.78
Beryo	6.74	30.12	13.5	0.65	0.2
Keremsa	7.1	25.18	17.13	0.013	0.145
Ferejete	6.91	29.76	12.34	0.047	0.52
Jajebenagasure	6	28.25	14.3	0.16	0.56
Zebimola	6.4	29.12	20.25	0.13	0.54

Where: Av.P, available phosphorus; CEC, cation exchange capacity SOC, soil organic carbon; TN, total nitrogen

3.2 Effects of nutrient omission on teff growth parameters

3.2.1 Teff plant height response to nutrients

Two year multi-location field experiment result show that the critical role of balanced nutrient application in boosting the yield and yield componets of teff on Vertisols of central Ethiopia. Full balanced fertilizer (NPKSZnB) consistently give the tallest plants, highlighting the key role of integrated nutrient management in enhancing vegetative growth [9, 8].

Omition of nitrogen (All – N) and phosphorus (All – P) led to the most substantial decrease in plant height, indicating that these both nutrients are the main limiting factors under the local soil conditions, consistent with recent Ethiopian studies [24, 25]. Excluding of Nitrogen reduced plant height to 86.2 cm and 92.9 cm in 2022/23 and 2023/24, respectively, compared with 128.9 and 113.2 cm under balanced fertilizer application. This reduction is attributed to nitrogen's essential role in cell devision and biomass production, which drive plant vigor and canopy development [25]. Similar reductions in plant height in rice have been reported in previous studies due to omission of nitrogen[27].

Phosphorus Excluding also significantly reduced plant height, particularly in the first season, highlighting its importance in root development and early crop growth. Phosphorus limitation in Vertisol soils has been widely reported due to fixation processes that reduce its availability, especially in Ethiopian highlands [24, 8]. There is minor response to potassium omission which is suggests that Vertisols in the study area may contain adequate native potassium reserves, aligning with previous reports on Ethiopian highland soils.

3.2.2 Teff Panicle Length response to nutrients

Panicle length mirrored the same trend to plant height (Table 4). Application of Balanced fertilization and A standard recommended nutrient package based on local agricultural guidelines produced significantly longer panicles than nutrient

omission treatments, confirming the key role of nitrogen and phosphorus in supporting both vegetative and reproductive growth [24, 8].

Omitting potassium, sulfur, zinc, and boron caused only minor, non-significant reductions in panicle length, indicating that these nutrients were either sufficient in the soil or not strongly limiting under the experimental conditions (Table 4). Nonetheless, secondary and micronutrients remain important for crop performance, as they enhance enzyme activation, hormone function, and reproductive development, with their effects often becoming more pronounced in intensive systems or nutrient-depleted soils [9]. The significant reduction in panicle length under phosphorus Exclusion further supports recent findings that phosphorus deficiency is a major constraint to crop performance on Ethiopian Vertisol soils [24]. This agrees with earlier findings that adequate N and P increase total dry matter and support panicle development [28].

Table 4
Combined Analysis of Plant Height and Panicle Length as Affected by NOT

Treatments	1st Year (2022/23)		2nd Year (2023/24)		Pulled	
	PH (cm)	PL (cm)	PH (cm)	PL (cm)	PH (cm)	PL (cm)
Full NPKSZnB (balanced fertilizer)	128.93^{a}	42.97^{a}	113.19^{ab}	40.78^{ab}	121.06^{a}	41.88^{a}
Omission of boron (All – B)	126.48^{ab}	42.44^{a}	109.35^{abc}	39.13^{abc}	117.91^{bc}	40.78^{a}
Omission of zinc (All – Zn)	126.03^{ab}	42.73^{a}	112.56^{ab}	40.51^{ab}	119.29^{abc}	41.62^{a}
Omission of sulfur (All – S)	124.88^{b}	41.91^{a}	113.52^{ab}	41.44^{a}	119.20^{abc}	41.68^{a}
Omission of potassium (All – K)	127.34^{ab}	43.03^{a}	113.78^{a}	40.18^{ab}	120.56^{ab}	41.60^{a}
Omission of phosphorus (All – P)	94.08^{c}	33.78^{b}	105.06^{c}	37.65^{c}	99.57^{d}	35.71^{b}
Omission of nitrogen (All – N)	86.22^{d}	30.34^{c}	92.90^{d}	34.20^{d}	89.56^{e}	32.27^{c}
Recommended nutrient package (RNP)	125.10^{ab}	42.67^{a}	111.86^{ab}	40.20^{ab}	118.48^{abc}	41.44^{a}
No fertilizer (control)	75.34^{e}	27.03^{d}	83.83^{e}	30.92^{e}	79.59^{f}	28.98^{d}
RNP + S_2 (additional sulfur)	125.02^{b}	42.33^{a}	109.02^{bc}	38.69^{bc}	117.017^{c}	40.51^{a}
LSD (5%)	**3.83**	**1.62**	**4.7**	**2.52**	**3.02**	**1.49**
CV (%)	**5.9**	**7.32**	**7.73**	**11.52**	**6.83**	**9.58**

Note: PH, plant height; PL, panicle length, Different letters show the significant difference between treatments and CV shows coefficient of variation

3.3 Tef grain yield, biomass yield and harvest index response to nutrients

3.3.1 Grain Yield

Two year multi-location field experiment combined analysis revealed that balanced nutrient application and treatments including secondary and micronutrients (All – B, All – Zn, RNP + S_2) repeatedly produced the highest grain yields across both seasons, spanning from 1,506 to 1,581 kg/ha. However, Excluding of nitrogen (All – N) and phosphorus (All – P) markedly reduced grain yield, with combined values of 548.2 and 895 kg/ha, respectively. The lowest yields were observed in the unfertilized control plots (438 kg/ha). The lowest grain yield obtained from N omitted plots indicates N cannot be substituted by any other nutrient and has the highest contribution in teff yield. This confirms that N is the most limiting nutrient for crop production in many areas of the world and its efficient use is not only important for the economic sustainability of cropping

systems, but also for safeguarding environment from pollution. This may be due to the role of N in chlorophyll formation and photosynthesis, while N deficiency reduces leaf area and accelerates senescence [29]. Moreover, under N deficiencies, a considerably large proportion of dry matter is partitioned to roots than shoots, leading to reduced shoot/root dry weight ratio [30] and consequently the grain yield. These results also confirm that phosphorus are the most limiting nutrients for teff production on Ethiopian Vertisols, as it is critical for enrgy transfer,root development, Photosynthesis and metabolism ,carbohydrate assimilation, and panicle development [8, 24]. Secondary and micronutrients such as boron and zinc, while less limiting under the study area soil conditions.

3.3.2 Biomass

Two year combine Analysis of multiplication Analysis result show that Aboveground biomass of teff resembled grain yield across nutrient omission treatments, with the peak values in plots obtain All fertilization, revealing the critical role of macro and micronutrients in plant growth and dry matter accumulation. Excluding of nitrogen (N) or phosphorus (P) markedly reduced biomass a yield, affirming their central role roles in photosynthesis and nutrient consumption. These findings are congruent with long-term NPK Exclusion studies in the North China Plain, where withholding N or P significantly decreased cereal biomass and grain yield whereas balanced fertilizer application sustained higher biomass yields and soil nutrient balance [26].

3.3.3. Harvest Index (HI)

The results of the analysis reveal that the highest HI values were recorded in treatment obtaining a standard recommended nutrient package based on local agricultural guidelines and a standard recommended nutrient package with additional sulfur treatments, indicating efficient translocation of assimilates to the grain under balanced fertility. In contrast, Exclusion of nitrogen (N) and phosphorus (P) markedly reduced HI, with No nutrient application at all showing the lowest values, highlighting that deficiencies in key macronutrients not only limit total biomass but also impair grain allocation. These findings lend support to previous studies which reveal that balanced fertilization improves harvest index, whereas N and P deficiencies reduce assimilate partitioning efficiency [26].

Table 5
:Two-Year Effects of Nutrient Omission on Biomass, Grain Yield, and Harvest Index

Treatments	1st year (2021/22)			2nd year (2022/23)			Combined analysis		
	BM (kg/ha)	GY (kg/ha)	HI (%)	BM (kg/ha)	GY (kg/ha)	HI (%)	BM (kg/ha)	GY (kg/ha)	HI (%)
Full NPKSZnB (balanced fertilizer)	5464.4^{ab}	1616.40^{a}	30.82^{b}	6677.7^{ab}	1506.39^{a}	24.04^{a}	6071.0^{abc}	1561.40^{ab}	27.43^{a}
Omission of boron (All – B)	5687.7^{a}	1676.73^{a}	30.82^{b}	6722.8^{ab}	1421.57^{ab}	22.73^{a}	6205.2^{ab}	1549.15^{abc}	26.77^{a}
Omission of zinc (All – Zn)	5827.1^{a}	1671.33^{a}	30.19^{b}	6845.5^{a}	1492.42^{a}	23.52^{a}	6336.3^{a}	1581.88^{a}	26.86^{a}
Omission of sulfur (All – S)	5074.7^{b}	1616.78^{a}	32.54^{ab}	6178.8^{b}	1384.63^{ab}	23.89^{a}	5626.8^{d}	1500.71^{abc}	28.22^{a}
Omission of potassium (All – K)	5222.3^{b}	1581.11^{a}	31.53^{ab}	6601.6^{ab}	1362.47^{b}	22.05^{a}	5911.9^{bcd}	1471.79^{c}	26.79^{a}
Omission of phosphorus (All – P)	2977.4^{c}	780.55^{b}	25.17^{c}	4432.6^{c}	1009.43^{c}	22.06^{a}	3705.0^{e}	894.99^{d}	23.61^{b}
Omission of nitrogen (All – N)	2569.5^{c}	642.68^{c}	25.31^{c}	3016.1^{d}	453.69^{d}	16.40^{b}	2792.8^{f}	548.18^{e}	20.85^{c}
Recommended nutrient package (RNP)	5095.5^{b}	1636.61^{a}	33.31^{a}	6299.5^{ab}	1356.19^{b}	23.39^{a}	5697.5^{cd}	1496.40^{bc}	28.35^{a}
No fertilizer (control)	2033.2^{d}	461.84^{d}	21.72^{d}	2291.7^{e}	414.45^{d}	17.51^{b}	2162.4^{g}	438.14^{f}	19.61^{c}
RNP + S_2 (additional sulfur)	5816.5^{a}	1669.82^{a}	30.61^{b}	6524.8^{ab}	1449.65^{ab}	23.23^{a}	6170.6^{ab}	1559.74^{ab}	26.92^{a}
LSD (5%)	**418.98**	**98.4**	**2.48**	**650.35**	**126**	**2.4**	**397.23**	**83.14**	**1.8**
CV (%)	**16.04**	**12.91**	**14.91**	**20.5**	**18.63**	**19.25**	**19.51**	**16.42**	**17.55**

Note

BM, biomass yield; GY, grain yield; HI, harvest index, Different letters show the significant difference between treatments and CV, coefficient of variation

4 Conclusion and Recommendations

The study highlights that teff yield and yield components on Vertisol soils of central Ethiopia is mostly restricted by nitrogen and phosphorus deficiencies, However, the omission of secondary and micronutrients such as sulfur, zinc, and boron did not substantially contribute to increases in teff yield and yield components. All nutrients applied (NPKSZnB) consistently maximized yield and yield components of teff including harvest index across all location and seasons,.

In light of these findings, it is recommended that fertilizer strategies for teff on Vertisols prioritize site-specific, balanced applications of nitrogen and phosphorus, complemented by secondary and micronutrients where deficiencies are detected. Adoption of nutrient omission trials and soil testing at the local level should be encouraged to refine fertilizer recommendations, improve nutrient use efficiency, and sustain soil fertility.

5 Future research directions

Future research should prioritize the development of site-specific, long-term nutrient management strategies for teff on Vertisols, integrating both macro and micronutrients while accounting for spatial variability in soil fertility and microclimatic conditions. Furthermore, the adoption of precision agriculture technologies, such as soil sensors and remote sensing, could enable real-time monitoring and targeted nutrient application. Finally, assessing the environmental implications of nutrient management including nutrient losses and greenhouse gas emissions will be critical for promoting sustainable intensification of teff-based cropping systems in central Ethiopia.

Declarations

Ethical statement

All experimental protocols and procedures were reviewed and approved by the Ethiopian Institute of Agricultural Research prior to implementation. The study was conducted in accordance with applicable institutional and national regulations governing agricultural field research. Each participant was aware of the aim of the study and gave their informed consent to participate and publication before starting the study

Consent for publication

Not applicable. This study does not include any individual person's data or personal information requiring consent for publication

Plant guidelines

Teff (Eragrostis tef) seeds used in this study were obtained from wolkite Agricultural Research. All planting, cultivation, and experimental procedures were conducted following national and institutional guidelines for crop research to ensure responsible and standardized field management

Competing interests

The authors declare no competing interests.

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Author Contribution

Teshome Bekele* conceived and designed the study, conducted experiments, analyzed the data, and drafted the manuscript. Tesfaye Yaekob provided supervision, validation, and critical revisions. Bethel Nekir assisted with field investigations, data collection, and manuscript review. Yitegasu Nurga contributed to methodology, data analysis, and manuscript editing. All authors read and approved the final manuscript.

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Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Figures

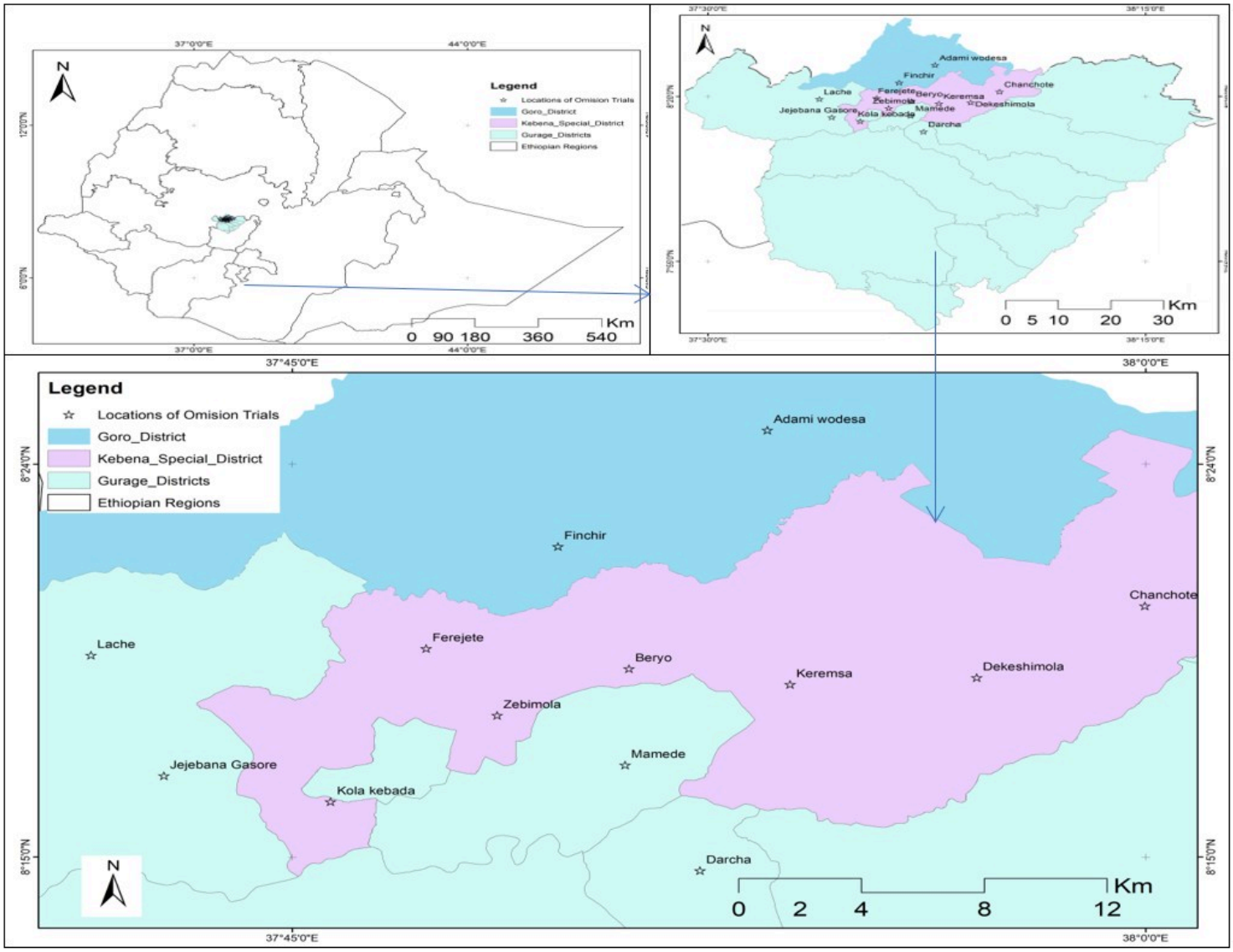


Figure 1

Figure 1: Map of study area



Figure 2

Figure 3: Illustration Showing Teff Sowing Conducted with a team of researcher and Technical Assistance.



Figure 3

Figure 4: Field status of the nutrient omission trial at the tillering stage