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Research Article

Comparison of Teff (*Eragrostis teff* (Zucc.) Trotter) Varieties in Response to Blended NPSZnB Fertilizer On-Farm and on Research Station

Zewdu Berhanu,[1] Mekoya Yifru,[2] Diriba-Shiferaw Geleta ,[3] and Feyera Liben[4]

[1]*Agriculture and Natural Resources Development Office, Yaya Gulale District, North Showa Zone, Oromia, Ethiopia*
[2]*Red Fox Ethiopia P.L.C., East Showa Zone, Oromia, Ethiopia*
[3]*Department of Horticulture and Plant Sciences, College of Agriculture and Environmental Science, Arsi University, P.O. Box, 193, Asella, Ethiopia*
[4]*Melkasa Agricultural Research Center, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia*

Correspondence should be addressed to Diriba-Shiferaw Geleta; dsphd2010@gmail.com

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Teff is an important food crop for the majority of Ethiopian; however, its productivity is constrained by lack of improved varieties and low soil fertility. Thus, field experiments were conducted in 2019/20 and 2020/21 main cropping seasons at Yaya Gulale district on the farm and at Adama district on research station, respectively to assess the response of teff varieties to NPSZnB-blended fertilizer. Three teff varieties (Dagim, Kora, Nigus) and five rates (0, 50, 100, 150, and 200 kg ha^{-1}) of blended NPSZnB fertilizer were evaluated on both sites. The treatments were laid out in a randomized complete block design of factorial arrangement with three replications at both locations. The highest biomass (7,639 kg ha^{-1}), grain (1,944 kg ha^{-1}), and straw (5,696 kg ha^{-1}) yields were recorded from variety Kora without statistical difference from variety Dagim as compared to variety Nigus on-station. More yields were also recorded from the station compared to on-farm. Highest biomass (7,341 and 8,868), grain (1,767 and 2,477), and straw (5,507 and 6,391 kg ha^{-1}) yields were recorded from on-farm and on-station sites, respectively, at 200 kg ha^{-1} NPSZnB. Also, the highest mean lodging index (82.56% and 63.89%) was observed on plots supplied with 200 kg ha^{-1} NPSB on-farm and on-station, respectively. In addition, the partial economic analysis showed that Dagim variety at 200 and 150 kg ha^{-1} NPSZnB generated better net benefits (533,745 and 106,204 Birr ha^{-1}) with higher marginal rate of returns (6,771.9% and 4,621.9%) on-farm and on-station, respectively. Therefore, it was concluded that the teff variety Dagim grown with 200 kg ha^{-1} at Yaya Gulale district (on-farm) and with 150 kg ha^{-1} NPSZnB applications at Adama district (on-station) is promising treatments for production and economic advantages of teff in Ethiopia.

1. Introduction

Teff (*Eragrostis teff* (Zucc.) Trotter) is a self-pollinated and warm season cereal crop that originated in Ethiopia and has been domesticated and used throughout the world due to its excellent nutritional value as grains for human consumption and as forage for adaptation for the diverse agro-climatic and soil livestock [1]. Teff is an economically superior commodity in Ethiopia and often commands a market price two to three times higher than maize, the commodity with the largest production volume in the country [2], thus, making teff an important cash crop for producers [3]. Teff has got both cultural and economic value for Ethiopian farmers, with more than 6 million households' lives depending on the production of teff [4]. It is a staple food for the majority of the population in Ethiopia, and its cultivation occupies about 27% of the total crop area allocated to cereals having a productivity of 1.88 t ha^{-1} [5]. The national average grain yield of teff in Ethiopia is relatively low, amounting to 1.88 t ha^{-1} [5]. However, using improved cultivars, blended NPSZnB fertilizer, and under good management practices, it yields up to 2.5 t ha^{-1}, while the yield potential under optimal

Table 1: Description of teff varieties used for the study.

Variety	Year released	Adaptation		Seed color	Maturity date	Grain yield ($t\,ha^{-1}$)	
		Altitude (m)	Rainfall (mm)			Research field	Farmers field
Dagim (DZ-Cr-438(RIL No.91A))	2015	1,700–2,400	950–1,800	Very white	80–113	2.5–3.2	2.0–2.8
Kora (DZ-Cr-438(RIL No.133BA))	2014	1,700–2,400	950–1,800	Very white	110–117	2.5–3.2	2.0–2.8
Nigus (DZ-Cr-429 RIL125)	2016	1,700–2,400	950–1,800	Very white	112–116	2.0–3.2	1.8–2.6

Source: Ministry of Agriculture [11].

management and when lodging is prevented as high as 4.5 $t\,ha^{-1}$ and the national average yield is 1.88 $t\,ha^{-1}$ [5, 6].

Despite covering the largest agricultural area of the country than any other types of grain and its importance, teff production and productivity are still very low due to traditional agronomic practices, nutrient deficiencies, and susceptibility of the crop to lodging [7]. The most important shortcoming in teff production is its inherent low productivities of local cultivars and low soil fertility status [8]. Following the soil fertility map made over 150 districts by the Ethiopian soils information system reported that Ethiopian soil lacks about seven nutrients; N, P, K, S, Cu, Zn, and B [9]. Of which, the study area particularly lacks N, P, S, Zn, and B, which are among the major teff yield-limiting soil nutrients [9, 10].

Soil fertility depletion is one of the major factors affecting teff production in Ethiopia; thus, farmers in the study area have been using diammonium phosphate (DAP) and urea fertilizers that only supply nitrogen and phosphorous nutrients for all cereal crops, including teff to increase their crop productivity [7, 9]. Also, soil inventory data from the Ethiopian soils information system (2013) revealed that in addition to nitrogen and phosphorus, sulfur, boron, and zinc deficiencies are widespread in Ethiopian soils, while some soils are also deficient in potassium, copper, manganese, and iron [9, 10]. These all are potentially hold back crop productivity due to continued utilization of N and P nutrients as per the blanket recommendation and thus recommend the application of customized and balanced fertilizers as reported by the Ethiopian soils information system report (2013). So that developing an alternative means to meet the demand of nutrients in plants using blended NPSZnB fertilizer that contains S, Zn, and B in addition to commonly used N and P fertilizers is crucial. Therefore, this study was undertaken with the objectives of evaluating the responses of teff varieties to blended NPSZnB fertilizer and to identify the economically feasible rate of blended NPSZnB fertilizer applied to teff both on the farm in Yaya Gulale district and on the research station at Adama district.

2. Materials and Methods

2.1. Description of the Study Areas. A field experiment was conducted at Gobola Kitila Kebele (Yaya Gulale District, North Showa Zone, Oromia-Ethiopia) on farmers' field and on research station at Melkasa Agricultural Research Center (Adama District, East Showa Zone, Oromia-Ethiopia) during the 2019/20 and 2020/21 main cropping seasons, respectively. The two study locations are found at 115 and 117 km from Addis Ababa to North and South East directions, respectively. Geographically, Yaya Gulale district is found at North of the capital city, Addis Ababa, at the latitude of 9.81°47′–10.08°11′ N, the longitude of 38°27′–38.67°43′E at an altitude of 3,167 m above sea level (study site) and Melkasa Agricultural Research Center (MARC) is located at 8°24′N and 39°21′E with an altitude of 1,550 m above sea level (Yaya Gulale District and MARC profile and meteorology 2019/20, 2020/21).

The agro-ecological zones of the two districts are midlands and lowlands/semi-arid with an annual maximum rainfall of 1,200 and 642 mm, and a temperature range was from 16–20°C to 14–31°C during the main cropping season of 2019/20 and 2020/21, respectively. The study area's main rainy season (*Kiremt*) is from July to August and the short season (*Belg*) extends from March to June. The soil texture was dominantly clay and clay loam, with slightly acidic and alkaline ranging from 6.14–7.0 to 7.0–8.2 pH (unpublished report of Yaya Gulale district Agriculture and Natural Resources Development Office, 2019/20 and Melkasa Agricultural Research Centre profile and meteorology, 2020/21). Major crops grown in the areas were teff, wheat, sorghum, barley, maize, and some species of legume crops. The land was continuously exploited and poor in fertility and particularly very low in organic matter as crop residues were not left in the fields after harvest basically for straw utilization and cultivation from season to season of both locations.

2.2. Experimental Materials. The teff varieties used for the study were Dagim (DZ-Cr-438(RIL-91A), Kora (DZ-Cr-438 RIL133B), and Nigus (DZ-Cr-429), which were released by Debrezeit Agricultural Research Center in 2015, 2014 and 2016, respectively (Table 1). NPSZnB (17.8% N, 35.7% P_2O_5, 7.7% S, 2.2% Zn, and 0.1% B) and urea (46% N) fertilizers were used as sources of nutrient supplement (Table 2).

2.3. Treatments Experimental Design and Layout. Fifteen treatments were developed by combining three teff varieties (Dagim, Kora, Nigus) with five blended NPSZnB rates (0, 50, 100,150, and 200 kg NPSZnB ha^{-1}). The treatments were laid out in randomized complete block design (RCBD) in a factorial arrangement replicated thrice. In accordance with the specifications of the design, a field layout was prepared. A plot size of 4 m^2 (2×2 m) with 20 cm row spacing and total of 10 rows were used. Plots and blocks were spaced by 0.5 and 1 m apart, respectively. The total area of the experimental field was 552 m^2 (12×46 m), including footpath and border. The field layout of the experiment was adjusted according to treatments and assigned randomly to each plot.

2.4. Experimental Procedures. Field was plowed and prepared according to local practices before planting at the locations.

Table 2: Fertilizer compositions of experimental treatments.

Treatments		Total composition of fertilizer in the treatment (kg ha^{-1})				
Blended NPSZnB rate (kg ha^{-1})	Nitrogen rate (urea; kg ha^{-1})	N	P_2O_5	S	Zn	B
0	0	0	0	0	0	0
50	46	54.90	17.85	3.85	1.10	0.05
100	46	63.80	35.70	7.70	2.20	0.10
150	46	72.70	53.55	11.55	3.30	0.15
200	46	81.60	71.40	15.40	4.40	0.20

Note: Utilized for the study at both locations.

Rows were made manually before sowing. The whole amount of NPSZnB fertilizer rates was applied at sowing time as the basal application to each plot. Nitrogen at the specified rates was applied in two splits in the form of urea: half at sowing and the remaining half was applied at vegetative growth. Seeds of teff varieties (Dagim, Kora, and Nigus) were manually drilled uniformly at the rate of 10 kg ha^{-1} in rows of 20 cm apart at a depth of about 3 cm in the early July of the cropping seasons. Harvesting was done in December 2019/20 and 2020/21, respectively, when the senescence of the leaves took place as well as the grains came out free from the glumes when pressed between the forefinger and thumb. The harvested total biomass yield was sun-dried until constant weight became achieved. The total dry matter was weighed by using field balance. Threshing and winnowing were done manually by hand on a mat. After threshing, the grain yield was weighed using a sensitive digital balance. All other cultural practices were uniformly applied to each plot as per the recommendations for the test location.

2.5. Soil Sampling and Analysis. Soil samples were taken randomly in a Zigzag pattern from the entire experimental fields of the two locations using an augur to the depth of 0–20 cm before sowing and composited into one sample. The collected soil samples were prepared following standard procedures under the shade, ground using mortar and pestle, and sieved through a 2 mm sieve. The sieved soils were stored in a clean plastic container for subsequent physical and chemical analysis. Soil textural class was determined by Bouyoucos Hydrometer Method [12]. Soil pH was determined in 1 : 2.5 soils to water ratio using a glass electrode attached to a digital pH meter [13]. Organic carbon (%OC) was determined by the wet digestion method [13]; then, the organic matter (%) was calculated by multiplying the OC% by factor 1.724. Cation exchange capacity (CEC) (C mol kg^{-1} soil) of the soil sample was first leached using 1 M ammonium acetate, washed with ethanol, and the adsorbed ammonium was replaced by sodium (Na). Then, the CEC was determined titrimetrically by distillation of ammonia that was displaced by Na [14]. Total nitrogen (%) was determined using the Kjeldhal method [15]. Available phosphorus (mg L^{-1}) was determined by the Olsen method [16]. Available sulfur (meq L^{-1} SO_4^{-2}) was determined turbidimetrically using a spectrophotometer method [17]. Exchangeable bases (potassium, magnesium, sodium, and calcium) were determined by Melich-3 methods [18].

3. Data Collected

3.1. Phenological and Growth Parameters. Days to 50% panicle emergence was determined as the number of days from sowing to the time when 50% of the plants were started to emerge the tip of panicles through visual observation. Days to 90% physiological maturity was determined as the number of days from sowing to the time when 90% of the plants were reached physiological maturity based on visual observation. It was indicated by senescence (turning to light yellow) of the leaves and vegetative parts, as well as free threshing of grain from the glumes when pressed between the forefinger and thumb. Plant height was measured at physiological maturity from the ground level to the tip of the panicle by hand meter from ten randomly pretagged plants in each net plot. Panicle length was the length of the panicle from the node where the first panicle branches emerged to the tip of the panicle by hand meter, which was determined from an average of ten pretagged plants per net plot at physiological maturity.

3.2. Yield and Yield Components. Total tillers (both effective and noneffective tillers) and productive tillers were determined by counting the tillers from 20 plants (randomly tagged during growth parameters measurement) per two middle rows of net plot at maturity and then converted to average per plant. Aboveground dry biomass yield was recorded at harvest maturity; the total biomass was weighted after sun drying for 3 days the harvested crops from the net plot area and then expressed in kg ha^{-1}. Grain yield was weighted after harvesting and threshing the crop from the net plot area, and the yield was expressed in kg ha^{-1}; then, the weight was adjusted to 12.5% moisture content. Thousand seed's weight from the bulk of threshed yield was determined by carefully counting the small grains by hand and weighing them using a sensitive balance (kg). After threshed, the straw yield was measured. The grain yield was measured by subtracting the grain yield from the total aboveground biomass yield (kg). The harvest index (HI) was calculated by dividing grain yield to total aboveground dry biomass yield and multiplied by 100.

The degree of lodging index (%) was assessed just before the time of harvest by visual observation based on the scales of 1–5, where 1 (0°–15°) indicates no lodging, 2 (15°–30°) indicate 25% lodging, 3 (30°–45°) indicate 50% lodging, 4 (45°–60°) indicate 75% lodging and 5 (60°–90°) indicate 100% lodging [19]. The scales were determined by the angle of inclination of the main stem from the vertical line to the

Table 3: Soil physical and chemical properties of the two experimental sites before planting.

Soil properties	On-farm		Research station		References
	Values	Ratings	Values	Ratings	
A. Physical properties					
Clay (%)	70		32		
Silt (%)	20		38		
Sand (%)	10		30		
Textural class	Clay		ClayLoam		Bouyoucos [22]
B. Chemical properties					
pH (1 : 2.5 H_2O)	6.14	Neutral	8.35	Basic	Tekalign [23]
Organic carbon (%)	1.28	Low	0.98	Low	Tekalign [23]
Total nitrogen (%)	0.22	Moderate	0.09	Low	Tekalign [23]
Available phosphorus (ppm)	5.49	Very low	3.92	Very low	Olsen et al. [16]
CEC (meq/100 g soil)	49.76	Very high	33.29	High	Landon [24]
Available sulfur (ppm)	14.44	Very low	2.23	Very low	EthioSIS [25]
Available boron (ppm)	0.27	Very low	0.36	Very low	EthioSIS [25]
Available zinc (ppm)	1.19	Very low	0.52	Very low	EthioSIS [25]

Source: Laboratory analysis results. CEC, cation exchange capacity.

base of the stem by visual observation. Each plot was divided based on the displacement of the aerial stem into all scales by visual observation. Each scale was multiplied by the corresponding percent given for each scale, and an average of the scales represents the lodging percentage of that plot. Data recorded on lodging percentage were transformed by the arcsine transformation method to normalize the error mean squared as described by Gomez and Gomez [20].

3.3. Data Analysis. A homogeneity test was done before the combined analysis. The two locations' data in terms of variety and fertilizers effects were separately collected and tested for homogeneity of variance at 5% level to compare the computed value with the tabulated value; then, after the two locations' data were compared as the treatments used across the locations due variety and fertilizers. Data collected were subjected to analysis of variance (ANOVA) using SAS version 9.2. Means of significant treatment effects were separated using the Fishers' protected least significant difference (LSD) test at 5% probability level.

3.4. Partial Economic Analysis. An economic analysis was done using a partial budget procedure described by CIMMYT [21]. Labor costs involved for the application of NPSZnB and urea fertilizer rates were recorded and used for analysis. The price of grain, straw yield of teff, and fertilizers were valued during the study years (2019/20 and 2020/21) at an average open market price at local towns, which were 35/50 ETB kg^{-1}, 0.50/1.60 ETB kg^{-1}, and 15/20 ETB kg^{-1} at Yaya Gulale and Adama Districts, respectively. The net returns (benefits) and other economic analyses were based on the formula developed by CIMMYT [21] and given as follows. Unadjusted grain and straw yields (kg ha^{-1}) were the average grain and straw yield of each treatment. Adjusted grain and straw yields (kg ha^{-1}) were the average grain and straw yields adjusted downward by a 10% to reflect the difference between the experimental yield and yield of farmers. Gross field benefit (ETB ha^{-1}) was computed by multiplying field/farm gate price that farmers received for the crop when they sold it as an adjusted yield. Total variable cost (ETB ha^{-1}) was calculated by summing up the costs that vary, including the cost of NPSZnB fertilizer (12.2/17.50 ETB kg^{-1}) and urea as N source fertilizer (10.50/15.50 ETB kg^{-1}) at the time of planting (July 2019/20 and 2020/21), and labor cost for application of fertilizers (4 persons ha^{-1}, each 80/100 ETB day^{-1}) at Yaya Gulale and Adama Districts, respectively. The costs of other inputs and production practices, such as labor costs for land preparation, planting, weeding, harvesting, and threshing, were considered the same for all treatments or plots. Net benefit (ETB ha^{-1}) was calculated by subtracting the total variable costs from gross field benefits for each treatment, and the marginal rate of return (%) was calculated by dividing change in net benefit by change in total variable cost. The dominance analysis procedure, as described in CIMMYT [21], was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using the technique were referred to as dominated and nondominated treatments, respectively. Identification of a candidate recommendation was from among the nondominated treatments. That is, the treatment which gives the highest net return and a marginal rate of return greater than the minimum acceptable to farmers (100%) was considered for the recommendation.

4. Results

4.1. Soil Physico-Chemical Properties. Data for preplanting sample soils of the two study sites for physicochemical properties generated through laboratory analysis was presented in Table 3.

4.2. Panicle Emergence. The interaction effects of location by variety had significantly ($P < 0.01$) influenced days to panicle emergence of teff, but this parameter was not affected by the interaction effect of fertilizer by variety and by the three

Table 4: Mean number of days to 50% panicle emergence of teff as influenced by interaction effects of location by variety and location by NPSZnB fertilizer rates.

Treatment	Panicle emergence (days)	
	On-farm	On-station
Varieties		
Dagim	58.87[a]	55.27[b]
Kora	58.80[a]	54.20[b]
Nigus	55.33[b]	45.93[c]
LSD (0.05)	2.71	
CV(%)	6.81	
NPSZnB (kg ha^{-1}) rates		
0	63.89[a]	56.00[cd]
50	60.22[b]	53.56[def]
100	57.11[bc]	51.56[fg]
150	54.89[cde]	49.89[gh]
200	52.22[efg]	48.00[h]
Mean	57.67	51.80
LSD (0.05)	3.28	
CV (%)	6.38	

Where; LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance level.

factors (location, variety, fertilizer) (Table 4). The earliest days to panicle emergence (55.33 and 45.93 days) of teff were recorded from the Nigus variety on both locations and from all varieties on the research station, while the latest was from Dagim and Kora varieties (58.80 and 58.80 days) on-farm, respectively (Table 4). This indicated that earlier panicle initiation was also recorded from on-station as compared to on-farm.

Days to panicle emergence of teff was also significantly ($P < 0.01$) influenced by the interaction effects of location and blended NPSZnB rates. The most days to 50% panicle emergence (63.89 days) of teff were obtained from the unfertilized plot on the farm site, while the fewest days to 50% panicle emergence (48 and 49.89 days) were obtained from an application of the highest rates (200 and 150 kg ha^{-1}) of blended NPSZnB fertilizer on the research station, respectively (Table 4). As the level of fertilizer applied became increased, the days taken to panicle initiation became earlier on both farm and station sites. Panicle was emerged earlier on the station than on a farm.

4.3. Physiological Maturity. Days to physiological maturity of teff were significantly ($P < 0.01$) influenced by the interaction effects of the three factors (study locations, varieties, and blended NPSZnB rates) (Table 5). The earliest days to physiological maturity (70.67 days) were recorded from variety Nigus fertilized by 200 kg ha^{-1} NPSZnB on station, while the latest days to physiological maturity (123 days) were recorded from variety Dagim on the control plot at on-farm site (Table 5). An earlier physiological maturity day was obtained from on-station (82.29) as compared to on-farm (113.13). Generally, the variety Nigus was matured earlier as compared to Kora and Dagim varieties. As the level of fertilizer applied became increased, the days taken to mature were decreased on both study sites.

4.4. Plant Height. The ANOVA showed that the interaction effects of locations, varieties, and NPSZnB fertilizer rates had significant ($P < 0.05$) influences on teff height (Table 5). The longest teff heights (122.67 and 119.33 cm) were recorded from Kora and Dagim teff varieties at 200 kg ha^{-1} NPSZnB rate applied on station, respectively, while the shortest teff height (65.47 cm) was recorded from variety Kora followed by Dagim and Nigus varieties (77.33 and 78.27 cm, respectively) on the control plots of the farm site (Table 5). The overall mean values of teff height at the two study locations indicated that a longer height (96.42 cm) was obtained on station as compared to a shorter height (90.43 cm) obtained on-farm. Teff heights were increased along the rates of fertilizer applied; the longest heights were recorded from plots fertilized with 150 and 200 kg ha^{-1} NPSZnB rates and the shortest from the control plots on-station (Table 5).

4.5. Panicle Length. Teff panicle length was significantly ($P < 0.01$) affected by location, variety, and NPSZnB fertilizer rates and their interactions (Table 6). The longest panicle length (58.67 cm) was recorded from variety Kora at 150 kg ha^{-1}, followed by the plot fertilized with 200 kg ha^{-1} NPSZnB (55.67 cm) on-station site. However, the shortest panicle length (12.00 cm) was recorded from variety Nigus on the control plot, followed by the plot fertilized with 50 kg ha^{-1} NPSZnB on-station with the same variety (Table 6). Generally, the panicle length was increased along with the fertilizer rate increment up to 150 kg ha^{-1} NPSZnB applied on both study locations, and a longer panicle was also produced from on-station (36.51 cm) compared to on-farm site (34.11 cm).

4.6. Total and Productive Tillers, and Thousand Seeds Weight. Study location, variety, and fertilizer rates had significantly ($P < 0.01$) influenced the number of total and productive tillers per plant, but their interaction did not affect the two parameters (Table 7). More numbers (3.67 and 2.18 plant^{-1}) of total and productive tillers were obtained from on-farm and on-station, respectively. A higher number of total tillers (3.53 and 3.60 plant^{-1}) was obtained from Dagim and Kora varieties as compared to Nigus variety (3.20 plant^{-1}), but productive tillers were nonsignificant due to variety. The highest number of total tillers (4.39 plant^{-1}) was produced with an application of the highest NPSZnB rate (200 kg ha^{-1}), while increased NPSZnB rates significantly increased the total number of tillers per plant. The highest number of productive tillers (2.36 and 2.11 plant^{-1}) was produced by 100 and 200 kg ha^{-1} NPSZnB applied, respectively. The lowest number of total and productive tillers (2.28 and 1.13 plant^{-1}) was obtained from the unfertilized or control plots, respectively (Table 7).

Thousand seeds weight of teff was significantly ($P < 0.01$) influenced by the effect of the study location, varieties, and NPSZnB fertilizer rates; however, their interaction did not statistically affect thousand seeds weight (Table 7). More thousand seeds weight (0.34 g) was obtained from on-farm

Table 5: Physiological maturity and height of teff as influenced by the interaction effects of location, variety, and NPSZnB fertilizer rates.

Treatments		90% physiological maturity (days)		Teff height (cm)	
Varieties	Fertilizer (kg ha^{-1})	On-farm	On-station	On-farm	On-station
Dagim	0	123.00^{a}	93.67^{h}	77.33^{k}	82.67^{ijk}
	50	118.33^{c}	91.67^{i}	101.63^{bcd}	86.33^{hijk}
	100	115.00^{d}	88.33^{j}	97.37^{cdefg}	97.33^{cdefg}
	150	110.00^{f}	85.33^{kl}	104.63^{bc}	106.00^{bc}
	200	110.00^{f}	82.67^{mn}	97.33^{cdefg}	119.33^{a}
Kora	0	120.33^{b}	89.67^{j}	65.47^{l}	93.33^{defghi}
	50	117.33^{c}	86.67^{k}	90.50^{efghij}	97.00^{cdefgh}
	100	113.33^{e}	84.00^{lm}	89.40^{efghij}	103.00^{bcd}
	150	110.00^{f}	81.33^{no}	98.93^{bcde}	108.33^{b}
	200	106.00^{g}	80.00^{o}	98.70^{bcdef}	122.67^{a}
Nigus	0	118.00^{c}	77.67^{p}	78.27^{k}	64.67^{l}
	50	115.00^{d}	75.67^{q}	87.63^{ghijk}	80.67^{jk}
	100	110.67^{f}	74.33^{b}	90.67^{efghij}	86.67^{ghijk}
	150	105.00^{g}	72.67^{r}	88.03^{fghijk}	93.00^{defghi}
	200	105.00^{g}	70.67^{s}	90.60^{efghij}	105.33^{bc}
Mean		113.13	82.29	90.43	96.42
LSD (0.05)		1.63		10.88	
CV (%)		1.02		7.13	

Where LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation. Means in column and row of the same parameter followed by the same letters are not significantly differed at 95% significance.

Table 6: Mean panicle length of teff as affected by the interaction effect of location, variety, and blended NPSZnB fertilizer rates treatments.

Treatments		Panicle length (cm)	
Variety	Fertilizer (kg ha^{-1})	On-farm	On-station
Dagim	0	30.40^{mn}	18.33^{q}
	50	38.53^{fg}	30.67^{mn}
	100	37.43^{gh}	37.00^{ghi}
	150	38.60^{fg}	53.33^{b}
	200	37.27^{gh}	47.33^{d}
Kora	0	26.77^{o}	27.33^{o}
	50	34.03^{jkl}	41.00^{f}
	100	32.87^{klm}	50.33^{c}
	150	35.03^{hijk}	58.67^{a}
	200	35.53^{hij}	55.67^{b}
Nigus	0	30.00^{n}	12.00^{s}
	50	33.20^{jkl}	15.00^{r}
	100	34.20^{jkl}	22.00^{p}
	150	32.50^{lm}	44.33^{e}
	200	35.30^{hijk}	34.67^{ijkl}
Mean		34.11	36.51
LSD (0.05)		2.47	
CV (%)		4.28	

Where LSD = least significant difference; CV = coefficient of variation. Means in column and row followed by the same letters are not significantly different at 95% significance level.

as compared to on-station. The highest thousand seeds weight of teff (0.33 g) was obtained from the variety Dagim, followed by Kora variety, and the lowest weight was recorded from variety Nigus (0.29 g). The highest thousand seeds weight of teff (0.34 g) was obtained from the plot applied with 200 kg ha^{-1} NPSZnB, and the lowest thousand seeds weight of teff (0.29 g) was obtained from the control plot (Table 7). The other applied fertilizer rates showed nonsignificant differences for thousand seeds' weights.

4.7. Biomass, Grain, and Straw Yields of Teff. Teff aboveground biomass, grain and straw yields were significantly ($P < 0.01$) influenced by the interaction effect of location by variety, and location by blended NPSZnB fertilizer rates, but the interaction effects of the three factors did not statistically influence the yields (Table 8). The highest aboveground biomass, grain, and straw yields (7,639, 1,944, and 5,696 kg ha^{-1}) were recorded from variety Kora on-station, followed by variety Dagim, while the lowest biomass, grain and straw yields (5,167, 1,270, and 3,896 kg ha^{-1}) were recorded from variety Nigus on-farm, respectively (Table 8). More biomass, grain and straw yields were obtained on station as compared to on-farm, and the yields obtained from the three varieties were not statistically different from each other on-farm.

The highest biomass, grain, and straw yields (8,868, 2,477, and 6,391 kg ha^{-1}) were recorded from teff fertilized with 200 kg ha^{-1} NPSZnB followed by those fertilized with 150 kg ha^{-1} NPSZnB (8,222, 2,227, and 5,995 kg ha^{-1}) on-

Table 7: Main effects of location, variety, and blended NPSZnB fertilizer rates on the number of total tillers, productive tillers, and thousand seed weight of teff.

Treatment	Total tillers (number plant^{-1})	Productive tillers (number plant^{-1})	Thousands seed weight (g)
Location			
On-station	3.22^{b}	2.18^{a}	0.28^{b}
On-farm	3.67^{a}	1.36^{b}	0.34^{a}
LSD (0.05)	0.26	0.21	0.014
Varieties			
Dagim	3.53^{a}	1.80	0.33^{a}
Kora	3.60^{a}	1.82	0.31^{b}
Nigus	3.20^{b}	1.69	0.29^{c}
LSD (0.05)	0.31	NS	0.014
NPSZnB (kg ha^{-1})			
0	2.28^{d}	1.13^{c}	0.29^{c}
50	3.06^{c}	1.48^{b}	0.31^{b}
100	3.56^{b}	2.36^{a}	0.31^{b}
150	3.94^{b}	1.77^{b}	0.31^{b}
200	4.39^{a}	2.11^{a}	0.34^{a}
LSD (0.05)	0.41	0.33	0.018
CV (%)	17.86	27.91	10.99

Where LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation; NS = nonsignificant. Means in column followed by the same letters are not significantly different at 95% significance level.

Table 8: Means of biomass, grain, and straw yields of teff as influenced by the interaction effects of location by variety and location by NPSZnB fertilizer rates.

Treatment	Biomass yield (kg ha^{-1})		Grain yield (kg ha^{-1})		Straw yield (kg ha^{-1})	
	On-farm	On-station	On-farm	On-station	On-farm	On-station
Varieties						
Dagim	5423^{c}	7019^{ab}	1294^{bc}	1654^{ab}	4129^{c}	5365^{ab}
Kora	5475^{c}	7639^{a}	1261^{bc}	1944^{a}	4175^{c}	5696^{a}
Nigus	5167^{c}	5850^{bc}	1270^{bc}	1126^{c}	3896^{c}	4725^{bc}
LSD (0.05)	1316		467		885	
CV (%)	29.74		16.85		26.14	
NPSZnB (kg ha^{-1})						
0	2411^{h}	4742^{g}	490^{f}	639^{f}	1921^{h}	4103^{fg}
50	4997^{fg}	5754^{def}	1126de	1089^{e}	3871^{g}	4666^{def}
100	5595^{efg}	6596^{cd}	1375^{cde}	1441^{cd}	4223^{efg}	5155^{cd}
150	6429de	8222^{ab}	1616^{bc}	2227^{a}	4813de	5995^{ab}
200	7341^{bc}	8868^{a}	1767^{b}	2477^{a}	5507^{bc}	6391^{a}
Mean	5355	6836	1275	1574	4067	5262
LSD (0.05)	884		323		625	
CV (%)	15.46		24.18		14.28	

Where LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation. Means in column and row for the same parameter followed by the same letters are not significantly different at 95% significance level.

station, respectively; while, the lowest biomass, grain, and straw yields (2,411, 490, and 1,921 kg ha^{-1}) were recorded from the control plots on-farm, respectively (Table 8). Generally, the control plots gave the lowest yields on both study stations. Application of 200 kg NPSZnB ha^{-1} had significantly improved teff biomass, grain, and straw yields by 67% and 46%, 74% and 72%, and 65% and 36% as compared to the lowest yields obtained from the control plots on-farm and on-station study sites, respectively. Similarly, highest biomass, grain, and straw yields produced by 200 kg ha^{-1} application were significantly improved by 24%/32% and 25%/35%, 22%/23% and 42%/56%, and 23%/30% and 19%/27% than teff fertilized with 100/50 kg ha^{-1} NPSZnB application on-farm and on-station, respectively. Also, production on-station had significantly

Table 9: Mean values of harvest index of teff as influenced by the interaction effects of location, variety, and blended NPSZnB fertilizer rates.

Treatments		Harvest index (%)	
Variety	Fertilizer (kg ha^{-1})	On-farm	On-station
Dagim	0	21.95^{defgh}	17.88^{hi}
	50	24.03^{bcdef}	20.12^{fgh}
	100	25.75^{abcd}	20.18^{efgh}
	150	24.88^{abcd}	27.89^{ab}
	200	21.99^{defgh}	27.82^{ab}
Kora	0	19.57^{gh}	14.06^{ij}
	50	19.83^{gh}	24.81^{abcd}
	100	23.34^{cdefg}	26.01^{abcd}
	150	24.46^{bcd}	27.94^{ab}
	200	25.29^{abcd}	28.68^{a}
Nigus	0	18.61^{h}	7.56^{k}
	50	24.89^{abcd}	10.17^{jk}
	100	24.24^{bcde}	18.76^{h}
	150	26.04^{abcd}	25.00^{abcd}
	200	24.92^{abcd}	27.06^{abc}
Mean		23.32	21.60
LSD (0.05)		4.12	
CV (%)		11.23	

Where LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation; Means in column and row followed by the same letters are not significantly different at 95% significance level.

increased mean biomass, grain, and straw yields of teff as compared to those produced on farms.

4.8. Harvest Index. The HI was significantly ($P < 0.01$) affected by the interaction effect of location, variety, and blended NPSZnB fertilizer rates (Table 9). The highest HI (28.68%) was recorded from variety Kora fertilized with 200 kg ha^{-1} NPSZnB without statistical difference from those plots fertilized with 150, 100, and 50 kg ha^{-1} on-station, and plot fertilized with 200 kg ha^{-1} NPSZnB on-farm by same variety, variety Dagim fertilized with 200 and 150 kg ha^{-1} NPSZnB on-station, and with 150 and 100 kg ha^{-1} NPSZnB on-farm, and variety Nigus fertilized with 200 and 150 kg ha^{-1} NPSZnB on both sites. The lowest HI (7.56%) was recorded from variety Nigus on the control plot without significant difference from plot fertilized with 50 kg ha^{-1} NPSZnB (10.17%) on-station (Table 9). The HI of teff was increased along with fertilizer levels applied on each variety planted. The two study sites were also showed significant differences on HI; more HI was obtained on-farm (23.32%) as compared to on-station (21.60%).

4.9. Lodging Index. The lodging index was significantly ($P < 0.01$) influenced by the interaction effects of location by variety and location by blended NPSZnB fertilizer rates (Table 10). The highest lodging index (46.67%) was recorded from variety Dagim on-station without statistical differences from others on both sites, except the lowest lodging index (28.33%) recorded from variety Nigus produced on-station.

Table 10: Mean values of lodging index (%) of teff as influenced by the interaction effect of location by variety and location by blended NPSZnB fertilizer rates.

Treatment	Lodging index (%)	
	On-farm	On-station
Varieties		
Dagim	42.73^{ab}	46.67^{a}
Kora	43.80^{ab}	40.00^{ab}
Nigus	39.47^{ab}	28.33^{b}
LSD (0.05)	17.95	
CV (%)	21.80	
NPSZnB (kg ha^{-1})		
0	11.67^{g}	16.67^{fg}
50	20.00^{fg}	25.00^{ef}
100	32.00^{de}	38.89^{cd}
150	63.78^{b}	47.22^{c}
200	82.56^{a}	63.89^{b}
Mean	42.00	38.33
LSD (0.05)	9.98	
CV (%)	26.48	

Where LSD (0.05) = least significant difference at 5% level; CV = coefficient of variation. Means in columns and rows followed by the same letters are not significantly different at 95% significant level.

The highest lodging index (82.56%) was recorded from teff plot fertilized with 200 kg NPSB ha^{-1} on-farm and the lowest (11.67% and 16.67%) from the control plots on-farm and on-station, respectively. The highest NPSZnB levels (150 and 200 kg ha^{-1}) had significantly increased the lodging index of teff as compared to the lowest levels on both sites. The mean values of teff lodging index on-farm and on-station were not statistically different (Table 10).

4.10. Partial Economic Analysis. As indicated in Tables 11 and 12, the highest net benefits (533,745 and 106,204 Birr ha^{-1}) with the highest marginal rate of returns (6771.9% and 4621.9%) were obtained from variety Dagim with an application of 200 and 150 kg ha^{-1} NPSZnB fertilizer on-farm and on-station, respectively. However, the lowest net benefits (434,869.25 and 59,506.97 Birr ha^{-1}) with marginal rate of returns of 3,010.3% and 2,625.2% were obtained from variety Dagim fertilized with 50 kg ha^{-1} NPSZnB fertilizer on-farm and on-station, respectively (Tables 11 and 12). The other fertilizer treatments with Kora and Nigus varieties became dominated, which may not be considered as economically feasible for producers.

5. Discussion

The studied teff crop has shown significant variations in days to panicle initiation, physiological maturity, plant height, panicle length, tiller number, thousand seeds weight, biomass yield, grain yield, straw yield, HI, lodging index, and partial economic feasibility due to location, varieties, and applied fertilizer. The latest panicle emergence was observed on Dagim and Kora varieties and on those teff produced without

Table 11: Summary of partial economic analysis of teff production due to the effects of varieties and blended NPSZnB fertilizer rates application on-farm.

Variety	NPSZnB rate (kg ha^{-1})	Adjusted grain yield (kg ha^{-1})	Adjusted straw yield (kg ha^{-1})	Total revenue (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Marginal rate of return (%)
Dagim	0						
Dagim	50	977.25	4,014.86	435,689.25	820	434,869.3	3,010.3
Dagim	100	1,314.11	4,263.11	472,304.48	1,640	470,664.5	1,370.8
Dagim	150	1,439.36	4,453.50	495,727.13	2,460	493,267.1	1,310.1
Dagim	200	1,627.82	4,800.51	537,025.04	3,280	533,745.0	6,771.9
Kora	0	968.57	1,885.50	222,449.69	0	222,449.7	0
Kora	50	1,073.46	3,426.54	380,224.91	820	379,404.9	D
Kora	100	1,270.18	3,658.39	410,295.47	1,640	408,655.5	D
Kora	150	1,420.93	4,260.32	475,764.51	2,460	473,304.5	D
Kora	200	1,533.75	5,430.54	596,734.85	3,280	593,454.9	D
Nigus	0	404.03	1,738.82	188,023.29	0	188,023.3	0
Nigus	50	1,069.18	3,216.53	359,074.67	820	358,254.7	D
Nigus	100	1,126.82	3,480.32	387,471.03	1,640	385,831.0	D
Nigus	150	1,505.53	4,279.82	480,675.51	2,460	478,215.5	D
Nigus	200	1,609.82	4,818.75	538,218.63	3,280	534,938.6	D

Where D = dominated treatments. ETB ha^{-1} = Ethiopian Birr per hectare; Market price of teff = 35 ETB kg^{-1}; Market price of straw = 0.5 ETB kg^{-1}; Cost of blended NPSZnB fertilizer = 750 birr per 50 kg, Labor cost for fertilizer application = 1 person for 50 kg, each at 70 ETB day^{-1}.

Table 12: Summary of partial budget analysis of teff production due to the effects of varieties and blended NPSZnB fertilizer rates application on-station.

Variety	NPSZnB rate (kg ha^{-1})	Adjusted grain yield (kg ha^{-1})	Adjusted straw yield (kg ha^{-1})	Total revenue (ETB ha^{-1})	Total variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Marginal rate of return (%)
Dagim	0						
Dagim	50	1,091.43	4,334.67	61,506.97	2,000	59,506.97	2,625.2
Dagim	100	1,241.10	4,934.07	69,949.51	3,250	66,699.51	3,041.7
Dagim	150	2,042.73	5,292.63	110,604.71	4,400	106,204.71	4,621.9
Dagim	200	2,252.43	5,838.57	121,963.21	5,750	116,213.21	2,544.7
Kora	0	634.77	3,883.23	37,951.67	500	37,451.67	D
Kora	50	1,392.57	4,213.53	76,370.15	2,000	74,370.15	0
Kora	100	1,692.27	4,810.77	92,310.73	3,250	89,060.73	0
Kora	150	2,431.17	6,271.83	131,593.43	4,400	127,193.43	0
Kora	200	2,594.70	6,451.83	140,057.93	5,750	134,307.93	0
Nigus	0	273.870	3,451.23	19,215.47	500	18,715.47	D
Nigus	50	455.67	4,049.1	29,262.06	2,000	27,262.06	D
Nigus	100	956.7	4,173.03	54,511.848	3,250	51,261.848	D
Nigus	150	1,538.37	4,621.77	84,313.332	4,400	79,913.332	D
Nigus	200	1,839.87	4,965.03	99,937.548	5,750	94,187.548	D

Where D = dominated treatments; ETB = Ethiopian Birr; Market price of teff = 50 ETB kg^{-1}; Market price of straw = 1.60 ETB kg^{-1}; Cost of blended NPSZnB fertilizer = 1,000 birr per 50 kg; Labor cost for fertilizer application = 1 persons for 50 kg, each at 100 ETB day^{-1}.

external fertilizer applied on-farm. Earliest panicle emergence was observed on variety Nigus and plot fertilized with 200 kg ha^{-1} NPSZnB on-station. The longest maturity days were observed on variety Dagim, followed by other varieties on the control plots of on-farm site, but the shortest maturity days were recorded from variety Nigus on-station at 200 kg ha^{-1} NPSZnB fertilizer applied. These might be due to the short life span of variety Dagim than the other varieties, and the sufficient amount of NPSZnB enhanced growth and development of teff owing to the essential elements under soil highly utilized for production. Earlier emergency and maturity were also recorded from on-station compared to on-farm, which might be due to the agro-ecological difference; the research station is located at the lower/hottest climate, and farm site is located at highland. The hastened panicle emergence and physiological maturity as a result of the highest rate of blended NPSZnB fertilizer applied could be due to early establishment, rapid growth, and development characteristics of the crop by the nutrients applied. The application of N hastened the days to heading, possibly because of the teff plants were able to take up sufficient N from the soil and consequently have enhanced the uptake of other nutrients, such as P, which might speed up the growth and development of the crop. This result is also in agreement with Assefa et al. [26], who reported that variety Dagim has taken more days (59) to 50% emerge panicles (head). This result is also in agreement with Solomon et al. [27], who reported that Dagim and Kora teff varieties took 114 and 113 days, respectively, to physiologically mature. Similarly, Abichu et al. [28] reported that N supplication had promoted the uptake of other nutrients, enhancing the growth and development of teff. This result is also in line with that of Berecha and Mokonin [29], who found that N and P_2O_5 applied at 64/46 kg ha^{-1} had significantly reduced days to the heading of teff over the control. Similarly, Getahun et al. [30] reported that the heading of teff plants was accelerated with an increased NP rate from zero to 69 kg N ha^{-1} and 30 kg P_2O_5 ha^{-1} fertilizer applications. Also, Yared et al. [31] and Melkamu et al. [9] reported that the highest days to 50% panicle emergence (49 days) and days to maturity (86.33 days) were obtained from unfertilized (control) treatment.

Similarly, the ANOVA showed that Kora and Dagim teff varieties produced the tallest teff height at 200 kg ha^{-1} NPSZnB applied on-station, but all varieties had produced the shortest height on the control plots of on-farm and on-station sites. This might be because of the genotypic characteristic of the varieties in responding to the applied nutrients and available in the soil and efficient in nutrient's utilization. Kora variety is more productive as compared to others at various sites, as reported by scholars like Solomon et al. [27]. Girma [10] also reported that Kora and Dagim varieties produced the highest heights (102.5 and 95.6 cm), respectively, at 200 kg ha^{-1} NPSB. The mean values of teff height on-station were higher compared to on-farm; this indicated that the research station might have good management and soil fertility status to increase the teff heights. This might be due to the effect of NPSZnB fertilizer as a combined application of N, P, S, Zn, and B nutrients significantly played a synergetic effect and vital role in cell division, elongation, and vegetative growth of plants [32]. Similarly, Wato and Negash [33] reported that higher N application (69 kg N ha^{-1}) was resulted in a taller teff height (94 cm) as compared to the control (82 cm) due to the direct effect of N on vegetative growth of plants. Okubay et al. [34] also reported maximum teff height (112.33 cm) on the plot supplied with the highest N rate (69 kg ha^{-1}), whereas the lowest height was obtained from the control plot of teff. Also, Yared et al. [31] obtained maximum teff height (105.72 cm) at a combined application of 150 kg NPS along with 69 kg N ha^{-1} from urea.

Application of NPSZnB fertilizer to teff varieties showed statistical variations for panicle length both on-farm and on-station and significantly increased along with increased rates of NPSZnB until 150 kg ha^{-1}. Variety Kora fertilized with 150 kg ha^{-1} NPSZnB has produced the longest panicle length, but variety Nigus has produced the shortest panicle length on the control plot at on-station. This is due to the enhanced growth height by the applied blended fertilizer rate with balanced nutrients that improved panicle length. Longer panicle was also produced from on-station as compared to on-farm, which might be due to soil nutrition and land management practices on research station. Similarly, Yared et al. [31] obtained a maximum teff panicle length (43.33 cm) at a combined application of 150 kg NPS and 69 kg N ha^{-1} from urea.

Statistically, more number of total tillers per plant (3.67) were obtained from on-farm, but more productive tillers per plant (2.18) were obtained from on-station, which might be due to the nutritional status of the location was varied. More total tillers were recorded from Dagim and Kora varieties compared to the variety Nigus. The application of NPSZnB fertilizer was significantly increased the number of total and productive tillers along the fertilizer rates on both sites. The increased number of tillers with the applied rates of NPSZnB might be due to the rapid conversion of synthesized assimilates, carbohydrates, and protein, and consequently, the increased in number and size of growing cells, ultimately resulting in an increased number of tillers and synergetic effects of the applied nutrients. The improvement in the total number of tillers with NPSZnB application might be due to the role of N, P, S, Zn, and B found in blended NPSZnB in developing radical and seminal roots during seedling establishment [35]. This result is in agreement with that of Fayera et al. [8], Kibebew [36], and Girma [10], who reported that application of blended fertilizer (69 kg N ha^{-1} + 46 kg P_2O_5 + 22 kg S ha^{-1} + 0.3 kg Zn ha^{-1}) and 150 and 200 kg ha^{-1} NPSB brought a significant increase in total tillers of teff as compared to unfertilized plot. In agreement with the results of this study, Fayera et al. [8] found that the highest productive tillers of teff were at the application of 200 kg ha^{-1} NPSZnB blended along 23 kg N ha^{-1} urea fertilizer. Also, a result obtained by Abebe et al. [37] showed significant differences in the number of total tillers per plant among different blended fertilizers (NPS) in durum wheat.

Significantly higher thousand seeds' weights were produced from on-farm, Dagim variety, and the plot received 200 kg ha^{-1} NPSZnB compared to other treatments. This is due to the genetic compositions of the varieties at various locations and management practices. Optimum nutrients' application with better compositions significantly improved thousand seeds' weight than those produced without fertilizer applied and lower rate as they increased the growth of the plant. Thousand seed weight is an important yield-determining component as reported to be a genetic character that is influenced least by environmental factors [9, 30, 34].

Teff varieties were statistically ($P < 0.01$) influenced on study locations in their biomass, grain, and straw yields. Variety Kora produced the highest biomass, grain, and straw yields without statistical differences from variety Dagim on-station, while the Nigus variety gave the lowest biomass, grain, and straw yields on the research station. However, the three teff varieties showed lower biomass, grain, and straw yields without statistical difference between them on-farm as compared to their yields on-station. The two study sites also showed significant differences in biomass, grain, and straw yields; more yields were obtained on-station compared to on-farm, which was improved by 21%, 19%, and 22%, respectively. This might be due to the land and agronomic management available on the research station compared to farm, and the nutritional status of the research station was better than the farmers' fields that influenced those varieties. Girma [10] and Assefa et al. [38] also reported that the highest grain yield (3,936 kg ha^{-1}) was recorded from Quncho and Dagim varieties, while the lowest grain yields (3,574 and 2,653 kg ha^{-1}) were recorded from variety Kora, respectively.

Application of higher rates of NPSZnB fertilizer (200 and 150 kg ha^{-1}) significantly produced the highest biomass, grain, and straw yields on-station, while the lowest biomass, grain, and straw yields were recorded from the control plots on both sites. This improved teff biomass, grain, and straw yields by 67% and 46%, 74% and 72%, and 65% and 36% at an application of 200 kg NPSZnB ha^{-1} as compared to the lowest yields obtained from the control plots on-farm and on-station, respectively. Similarly, the highest biomass, grain, and straw yields produced by 200 kg ha^{-1} application were significantly improved the teff yields than those fertilized with 100 and 50 kg ha^{-1} NPSZnB on-farm and on-station. However, the yields produced on-station was higher than those produced on-farm at each level of fertilizer applied. This increment might be due to optimum nutrients applied in combined elements and supplemental nitrogen applied from urea along the soil's available nutrition. The increase in the yields at the highest rate of NPSZnB might have resulted from an improved root growth and increased uptake of nutrients favoring better growth of the crop and yield attributes by the synergetic effect of the five nutrients (NPSZnB) supplied to the study soils at both locations. This result is also in agreement with the research findings of Fissehaye et al. [39], who reported a significant increase in total biomass of teff (3,720 kg ha^{-1}) as a result of 69 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} application. Similarly, Fayera et al. [8] reported that teff received blended nutrients (69 kg N ha^{-1} + 46 kg P_2O_5 + 22 kg S ha^{-1} + 0.3 kg Zn ha^{-1}) under row planting produced the highest yield (4,155 kg ha^{-1}) which had increased by 30% and 378% as compared to those fertilized with urea along DAP and control plots, respectively. Similar results were also found by Melkamu et al. [9], Abichu et al. [28], Wato and Negash [33], Getahun et al. [30], and Okubay et al. [34], who indicated that the highest straw yield (3,136–9,652 kg ha^{-1}) of teff was obtained in response to the application of higher rates of N application (46–69 kg ha^{-1}). This is attributed to the production of a significantly higher number of tillers, longer panicles, and taller plants that enhanced greater biomass yield. Similarly, the maximum total tiller (1,291 plant m^{-2}), productive tiller (1,192 plant m^{-2}), aboveground biomass yield (10,038 kg ha^{-1}), grain yield (2,162 kg ha^{-1}), thousand kernel weight (0.355 g), straw yield (7,876 kg ha^{-1}) and lodging index (70.83%) were recorded at the highest rate of blended NPS (150 kg NPS ha^{-1}) applied [31].

Significantly highest HI was obtained from Dagim, Kora, and Nigus varieties on both study sites with higher NPSZnB fertilizer rates applied (150 and 200 kg ha^{-1}). This might be due to an increase in biomass conversion to grain by optimum growing resources like nutrients and water in addition to genetic improvement and agronomic management practices. HI indicated the balance between the productive parts of the plant and the reserves, which form the economic yield. Higher HI indicated the presence of good partitioning of biomass yield to the economic yields of teff. Generally, the highest HI (28.68%) was recorded from variety Kora fertilized at 200 kg ha^{-1} NPSZnB application on-station, and the lowest HI (7.56%) was recorded from variety Nigus on the control plot. However, Girma [10] obtained the highest HI (29.63%) from the variety Quncho and the lowest HI (26.87%) from the variety Kora.

The lodging index of teff was varied statistically due to varieties and fertilizers applied across the study location. A higher lodging index was recorded from the three varieties on both study sites except the lower observed on-station by the Nigus variety. However, the lodging index due to variety is lower than due to fertilizer applied. The highest fertilizer rates (150 and 200 kg NPSZnB ha^{-1}) applied had caused the highest teff lodging at both locations, but the lower rates and control plots had caused a lower lodging index at both locations. This might be due to the enhanced height and growth of the crop by higher rates of nutrients supplied and higher rates of total nitrogen from 150 and 200 kg ha^{-1} NPSZnB along supplemental urea applied. These enhanced fast vegetative growth, plant height, and succulent stem elongation of teff, and the wind prevailed in the study area during the late vegetative growth period. Though the lodging percent is high, as it occurred mostly after the maturity of the crop, the yield reduction was not significant. This result was also in line with the findings of Berecha and Mokonin [29], who reported the highest lodging of teff (74%) at a rate of 64/46 kg ha^{-1} N/P_2O_5 applied. Likewise, Fayera et al. [8] reported the highest lodging percentage (79.74%) of teff with the highest rate of NPK (138 kg N ha^{-1} + 55 kg P ha^{-1} + 0 kg K_2O ha^{-1}) applied.

Also, the applied fertilizer at various rates on teff varieties showed significant variation in partial economic analysis on both study sites; the highest net benefits and marginal rate of returns were obtained from variety Dagim at an application of 200 and 150 kg ha^{-1} NPSZnB on-farm and on-station, respectively. This indicated that the farmers' farmland management practices are less than that of research stations, which increased the amount of fertilizer required for teff cultivation. Also, the lowest net benefits and marginal rate of returns were obtained from the same variety Dagim, which was fertilized with 50 kg ha^{-1} NPSZnB on both study sites. However, other varieties were dominated; thus, Dagim variety at an application of 200 and 150 kg ha^{-1} of blended NPSZnB fertilizer applied is economically beneficial as compared to the other treatments in the study sites of Yaya Gulale (farm) and Adama (station) districts, respectively, because the highest net benefit and the marginal rate of return were above the minimum level (100%). Similarly, Yared et al. [31] reported that the combined application of 150 kg NPS and 46 kg N ha^{-1} gave the highest economic benefit of 61,315.41 Birr ha^{-1} with a marginal rate of return of 852.50%.

6. Conclusion

Better teff growth, panicle length, tillers number, seeds weight, and yields were produced by higher rates of NPSZnB fertilizer applied on both sites and by Dagim and Kora varieties as compared to Nigus variety on-farm and on-station. More growth and yields were also produced on-station as compared to on-farm. The highest grain (1,767 and 2,227 kg ha^{-1}) yields were recorded from variety Dagim at 200 and 150 kg ha^{-1} NPSZnB with better net benefits (533,745 and 106,204 Birr ha^{-1}) and higher marginal rate of returns (6,771.9% and 4,621.9%) on-farm and on-station, respectively. Thus, Dagim variety at an application of 200 and 150 kg ha^{-1} NPSZnB rates is more economical and recommended as compared to the other treatments in the study sites of Yaya Gulale (farm) and Adama (station) districts, respectively.

For teff production in different parts of Ethiopia, increasing teff yield with acceptable grain yield from different combined treatments with an optimum application of blended NPSZnB fertilizer rate at various locations is very important in the future. Thus, soil management and crop improvement are very crucial for better teff productivity in line with agronomic practices. Moreover, emphasis and consideration should be given for the future research in similar topics; since the experiment should be approved on various locations with different varieties and fertilizer types according to their specific agro-ecologies.

These works put an image and directions for others in the area to further undertake research and innovations to improve the crop, soil, and management practices, especially on farmer's fields. Most Ethiopian farmlands are poor in management which puts insights for researchers to address the challenges and improve the productivity of the various cultivars.

Data Availability

The required data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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