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Response of Tef (*Eragrostis tef* (Zucc.) Trotter) to Balanced Fertilizer in Wolaita Zone, Southern Ethiopia

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Abstract

Tef is grown as an important domestic cereal in Ethiopia. Currently, global attention is given for it particularly as a "health food" due to the absence of gluten and gluten like proteins in its grains. Regardless of its wider adaptation, productivity of tef is low in the country with the national average grain yield of 1.379 tons·ha^{-1}. This is mainly because of low soil fertility and severe organic matter depletion intensified by low rate of chemical fertilizer application. This study was conducted to evaluate effects of balanced fertilizers on the yield, yield components of tef and to determine economic feasibility for tef production in Wolaita. The experiment was laid out in a randomized complete block design (RCBD) with sixteen treatments replicated three times. The treatments consist of factorial combinations of four rates of K (Potassium) (0, 25, 50, and 100 kg/ha) and four rates of NPSB (Nitrogen, Phosphorus, Sulfur and Boron) (0, 50, 100, 200 kg/ha) fertilizers. Fertilizer types such as urea (46-0-0), NPSB (18.9-37.7-6.95-0.1) and K (0-0-60) were used as a source of nutrients. The soil analysis result indicated that, most of the nutrients are below optimum level to support the potential crop production. This may be related with reduced farm management practices and continuous cropping with little or no fertilizers input. In this study, it was found that, the combined application of NPSB and K fertilizers had a significant effect on growth, yield and yield components of tef. Among the treatments studied, NPSB (100 Kg/ha) and K (50 Kg/ha) gave greater grain yield. Furthermore, this treatment enhanced growth and yield related parameters compared to the control treatment. Thus, it is conceivable to recommend each to attain greater grain yield of tef in the study area. However, it is desirable to undertake further research across soil type, years and locations to appeal comprehensive recommendation on a wider scale.

Keywords

Balanced Fertilizers, Tef, Yield, Soil Fertility

1. Introduction

Among cereal crops, tef, wheat and maize represent 90 percent of total cereal planted area and 89 percent of total cereal production. Since the 1960s, tef has accounted for the largest share of cereal cultivated area. However, the tef share has been declining gradually over the last four decades to make room for other cereals, mainly maize, whose share increased by almost 8 percent over the same time period [1].

In Ethiopia, tef is a major staple. It is the most important crop in terms of cultivation area and production value [2]. In 2017, tef accounted for about 24% of the nationwide grain-cultivated area, and nearly half of the small holder farmers grew it between 2004 and 2014 [3]. For dietary requirements, the country relies on tef for two-thirds of the daily protein intake and 11% of the per capita caloric intake [4].

The most common utilization of tef in Ethiopia is the fermented flatbread called injera [5]. [4] described this traditional flatbread as a soft, thin pancake with a sour taste. The most preferred form of the injera is one made from pure tef flour. Injera mixed with other flour such as wheat or sorghum is considered inferior. Other utilizations of tef include local alcoholic beverages called tela and katikala, and porridge [6]. Additionally, tef plant residues could be used as fodder for livestock, and often incorporated as construction materials [7].

Tef is an economically superior commodity in Ethiopia. It often commands a market price two to three times higher than maize, the commodity with the largest production volume in the country as in [8], thus making tef an important cash crop for producers [6]. Due to the high price, the urban affluent consumers consume relatively more tef than the rural poor [4]. Studies estimate that annual urban consumption of tef is 61 kg per capita on average whereas 20 kg for rural [5]. Outside Ethiopia, global consumers following the super-food wave are willing to pay premiums for tef [5]. Various tef-based products are developed to capture the premium market in the form of bread, porridge, muffin, biscuit, cake, casserole and pudding.

Nevertheless, tef has shortcomings to become an income-generating global commodity for Ethiopian producers. Some of the shortcomings are low yields compared to other major cereals, high labor-input requirement, lack of infrastructure, and limited or inefficient market [9].

Cereals are an important dietary protein and energy source throughout the world. Tef is grown as important cereal in Ethiopia [10]. It is national obsession and is grown by an estimated 6.3 million farmers. It has also recently been receiving global attention particularly as a "health food" due to the absence of gluten and gluten like proteins in its grains [11].

Tef has significantly highest share in Ethiopia in area of production. It was reported that tef covered 22.23% of the total area under cereal production followed by maize (16.39%) in 2013 [12]. According to the same report, tef is also the major crop grown in North shoa covering more than 28% of the total area under grain production.

Tef performs well at an altitude of 1800 - 2100 m a s l, annual rainfall of 750 - 850 mm, growing seasons rainfall of 450 - 550 mm and a temperature of 10˚C - 27˚C although it can adapt wide range of agro climatic conditions [13]. Moderately fertile clay and clay loam soils are ideal for tef. It can also withstand moderate water logged conditions [14].

Regardless of its wider adaptation, productivity of tef is low in the country with the national average grain yield of 1.379 tons·ha^{-1}. This is mainly because of low soil fertility and severe organic matter depletion aggravated by low rate of chemical fertilizer application. The rate of chemical fertilizer application is low in the country due to unaffordable price for resource-poor smallholder farmers [15].

There are different blanket fertilizer recommendations for various soil types of Ethiopia for tef cultivation. This is due to its cultivation in different agro-ecological zones and soil types, having different fertility status and nutrient content. Accordingly, N/P recommendation rates by the Ministry of Agriculture were set at 55/30, 30/40, and 40/35 N/P kg·ha^{-1} for tef crop on vertisols, Nitosols, and cambisols, respectively across the country [16]. However, 100 kg DAP·ha^{-1} and 100 kg·urea·ha^{-1} were set by the Ministry of Agriculture and Rural Development later [17]. Those blanket recommendations brought generally, an increase in yield of improved cultivars ranging from 1700 to 2200 kg/ha [18]. Accordingly, the average national yield in the year 2010 reached 1200 kg/ha [19]. However the recommendations do not work for all production aspects of various soil types of different regions. It is in fact possible to increase the yield potential of tef via optimizing nutrient supply to the soil. Determination of optimum fertilizer rates for specific soil types is vital for overcoming the problem that arose from the use of blanket fertilizer recommendation.

The proper rates of plant nutrients can be determined by knowledge about the nutrient requirement of the crop and supplying power of the soil. However, Generally in Ethiopian particularly in Wolayta zone farmers have only applied chemical fertilizers di-ammonium phosphate (DAP) and urea to increase crop yields for about five decades and this didn't consider soil fertility status and crop requirement. For instance, in southern Ethiopia, farmers apply 100/50 kg·ha^{-1} DAP/Urea for tef irrespective of the heterogeneity of the farm areas. In contrast to this, as [20] [21] [22] and [23] reported that agricultural fields are not homogenous and soil macro nutrient status is highly variable. In addition to this, DAP and urea supply only N and P but not other nutrients such as K. This omission of K from the fertilizer package was due to the fact that about four and half decades ago, when the fertilizer was tested in the national fertilizer demonstration initiative carried out by the Ministry of Agriculture and the Food and Agriculture Organization of the UN, no consistent trend was observed. In addition, a soil fertility survey conducted by [24] found no K deficiency in Ethiopian soils. However, as in [25] and [26] reported the deficiency of K in some Ethiopian soils. In addition to this, findings of the EthioSIS soil fertility mapping project in Ethiopia reported the deficiency of K, S, Zn, B and Cu in addition to N and P in major Ethiopian soils and thus recommended customized and balanced fertilizers [27] [28]. Moreover, as in [21] [22] [29] and [30] reported that S content in the soils they studied were found to be very low in some Ethiopian soils. Future gains in food grain production will be more difficult and expensive considering the increasing problem of multi nutrient deficiencies.

This study was conducted with the following objectives.

- To evaluate effects of balanced fertilizers on the yield, yield components of tef.
- To determine economic feasibility of balanced fertilizers for tef production in Wolaita.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted in selected districts of Wolaita zone, southern Ethiopia. The study districts or *woredas* were purposefully selected as they are among the districts where test crop production has largely been dominated. The districts are Humbo, Damot gale and Damot Sore Woredas. The study area is located between 037˚35'30"E - 037˚58'36"E and 06˚57'20"N - 07˚04'31"N and the elevation ranges between 1473 to 2873 meters above sea level (m.a.s.l). The ten years (2006-2016) mean annual precipitation of the study area was about 1355 mm. The area has a bimodal rainfall pattern and about 31 and 39% fall during autumn (March-May) and summer (June-August) seasons, respectively. The mean monthly temperature for the last ten years (2006-2016) ranges from 17.7˚C - 21.7˚C with an average of 19.7˚C [31].

According to traditional agro-ecological zone classification of Ethiopia, the area is predominantly characterized by mid highland agro-ecology. Besides, small portion of highlands in Damot Gale and Sodo Zuria districts and very small pocket lowland areas in Damot Sore districts are identified.

Eutric Nitisols associated with Humic Nitisols are the most prevalent soils in Wolaita Zone [32]. These are dark reddish brown soils with deep profiles. Agriculture in the study area is predominantly smallholder mixed subsistence farming and is dominantly rainfed. Continuous cultivation without any fallow periods coupled with complete removal of crop residues is a common practice on cultivated fields. Farmers in the study area use DAP, urea and farmyard manure (FYM) as sources of fertilizers [22].

The major crops grown in the study area include tef (*Eragrostis tef* (Zucc.) Trotter), maize (*Zea mays* L.), bread wheat (*Triticum aestivum* L.), haricot bean

(*Phaseolus vulgaris* L.), field pea (*Pisum sativum* L.), potato (*Solanum tuberosum*), sweet potato (*Ipomea Batatas*), taro (C*olocasia esculenta*), enset (*Ensete ventricosum*) and coffee (*Coffea arabica*). The vegetation is dominated by eucalyptus trees (*Camaldulensis spp.*). Remnants of indigenous tree species such as croton (*Croton macrostachyus* Hochst. ex Rich.), cordia (C*ordia Africana* Lam.), *Erythrina* spp., podocarpus (*Podocarpus falcatus*) and Juniperus (*Juniperusprocera*) are also present [22].

2.2. Experimental Materials

Tef variety named Areka-1; its pedigree is Dz-01-974x Dz-01-2788, which was developed and released by Areka Agricultural Research Centre in 2017 was used for the experiment. It is high yielding White seeded Cultivar adapted to wide range of altitudes. Nitrogen source used for the experiment was Urea. Balanced fertilizers NPSB (Nitrogen, Phosphourus, Sulfur, Boron) was used and Potassium was also used.

2.3. Experimental Design

The experiment was laid out in a randomized complete block design (RCBD). There were sixteen treatments replicated three times (**Table 1**). The treatments consists of factorial combinations of four rates of K (0, 25, 50, and 100 kg/ha) and four rates of NPSB (0, 50, 100, 200 kg/ha) fertilizers. Fertilizer types such as urea (46-0-0), NPSB (18.9-37.7-6.95-0.1) and K (0-0-60) were used as a source of nutrients.

Table 1. Balanced fertilizer treatments.

Treatment and formula	NPSB	K
T_1 = Control (Farmers who, not use any fertilizer)	0	0
T_2	0	25
T_3	0	50
T_4	0	100
T_5	50	0
T_6	50	25
T_7	50	50
T_8	50	100
T_9	100	0
T_{10}	100	25
T_{11}	100	50
T_{12}	100	100
T_{13}	200	0
T_{14}	200	25
T_{15}	200	50
T_{16}	200	100

2.4. Experimental Procedure

The experimental field was prepared by using local plough (maresha) according to farmers' conventional farming practices. The field was ploughed four times, the first plough at the end of May and the fourth during the middle of July before planting the crop. In accordance with the specifications of the design, a field layout was prepared and each treatment was assigned randomly to experimental units within a block. A 2 m × 3 m (6 m^2) was the size of each experimental unit. The blocks were separated by 1 m wide-open spaces; whereas the plots within a block were 0.5 m apart from each other. The seed was sown in mid July at rate of 10 kg/ha mixed with soil.

2.5. Agronomic Data Collection

The data collected include plant height, panicle length, number of seeds/panicle, spick length, tllering number, Grain yield, straw biomass, lodging percentage, days to 50% emergency, days to 75% maturity, and harvest index. The following methods and procedures were used to obtain and/or record the above data during the experimental period.

Days to 50% emergence was determined and recorded using one by one quadrant for each treatment and estimated visually as the number of days from planting to 50% of the plants emerged in each plot. Lodging percentage was estimated as the proportion of plants lodged in each plot and determined through visual assessment by estimating the percentage of plants lodged at a time of harvest. Plant height (cm) was recorded by measuring from the base of the plant to the tip of the plant panicle by taking ten plants from each plot at maturity stage. Days to 75% maturity was determined by counting the number of days from emergence to the period when 75% of the plants had reached the physiological maturity based on visual observations.

Seeds weight/panicle: is the average seed weight of the main panicle at harvest in gram. Averagely five randomly selected pre-tagged plants were taken. Grain yields were determined by harvesting and threshing all the plants in the 2 m × 3 m = 6 m^2 net harvest area of each plot and expressed in t/ha. Above ground biomass yields were recorded by weighing all the plants in the 2 m × 3 m = 6 m^2 of each plot that was harvested close to the ground surface and expressed in t/ha.

Harvest index was calculated from the ratio of the total grain yield threshed to the total biomass yield harvested from each plot.

2.6. Soil Analysis

One representative composite sample was taken from 0 to 20 cm depth from the entire field before planting. Physico-chemical analysis (soil texture, bulk density, soil pH, OC, TN, Available P, K, S, B, Zn, Cu and Mn) from each plot after harvest was analyzed by using standard procedures. The collected samples were air-dried and passed through 2 mm sieve to remove large particles, debris and stones. The sieved samples were analyzed for pH in 1:1 soil to water ratio using the Coleman's pH meter. Available P, available S, exchangeable basic cations (Ca, Mg and K) and extractable micronutrients (Fe, Mn, Zn, Cu and B) were determined using Mehlich-III multi-nutrient extraction method [33]. Organic carbon was determined by Wakley and Black procedure. Organic matter was estimated as organic carbon multiplied by 1.724. Total Nitrogen was determined by the micro Kjeldahl method. Textural analysis was analyzed by hydrometer method.

Economic Analysis

Economic analysis was performed to investigate the economic feasibility of the treatments. Partial budget, dominance, marginal and sensitivity analyses was used. The average yield was adjusted downwards to reflect the difference between the experimental plot yield and the yield farmers will expect from the same treatment. The average open market price (Birr·kg^{-1}) for different crops and the official prices of N, P, NPSB and K fertilizers was used for analysis. For a treatment to be considered a worthwhile option to farmers, the minimum acceptable rate of return (MARR) should be 100% [34], which is suggested to be realistic. This enables to make farmer recommendations from marginal analysis.

2.7. Data Collected

Plant height was measured at mid-head setting stage by measuring ten randomly selected plants from ground level to the top of the spike termination node and averaged for a single reading.

Number of tiller per plant was counted by ten randomly selected plants and values averaged for a single reading. Shoot dry weight per plant was measured at harvest by measuring ten randomly selected plants and averaged for a single reading. Spike length was measured from ten randomly selected spikes at harvest from each plot through measuring tape. 1000-grains weight (g) was measured at harvest and weighed on top loading digital balance and its averaged was taken as 1000-grain weight. Grain and biological yield were recorded at three central rows harvested in each experimental unit. Subsequent sample was oven dried at 70˚C for maximum 48 h to estimate dry matter yield. Harvest index was calculated as a ratio of grain yield to total biological yield.

2.8. Data Analysis

The data collected was statistically analyzed using the Analysis of Variance (ANOVA) procedures. The treatment means was separated using the Duncan Multiple Range Test (DMRT) at 5% level of probability.

3. Results and Discussion

3.1. Soil Physico-Chemical Properties

The result of pre-planting soil analysis shown that, the experimental soil is clay in texture (45% sand, 13% silt and 42% clay). Soil texture is a fundamental soil property which in practice the farmer can do little to modify. It is also closely related to the water-holding capacity of soils, since loams and clays hold more water than sandy soils [35]. Thus, the experimental soil has good water holding capacity, which creates a suitable growing media for cereal crops. Tef is characteristically grown on such soils which holds sufficient amount of residual soil moisture. The soil was strongly acidic in reaction with the pH (H_2O 1:2.5) value of 5.12.

The total N, available P, OC and CEC of the soil before planting were 0.1%, 8.44 mg·kg^{-1}, 1.18%, and 7.75 cmol (+) kg^{-1}, respectively (**Table 2**). According to Havlin soils are classified depending on their total N content in percentage (%), as very low (<0.1), low (0.1 to 0.15), medium (0.15 to 0.25), and high (>0.25). Thus, the soil of the study site has low total N content. Olsen classified available P content of the range < 5 as very low, 5 to 15 as low, 15 to 25 as medium and >25 mg·kg^{-1} as high. Thus, the soil of the study site has low P. According to Landon the soil organic carbon content ranges from 1% to 2%, 2% to 4%, and 4% to 6% are rated as low, medium and high, respectively. Thus, the OC content of the soil is considered as low before planting. The CEC ranges from 5 to 15, 15

Table 2. Selected physico-chemical properties of experimental soil.

Parameter	Value	Interpretation	Reference
Particle size %			
Sand	45		
Silt	13		
Clay	42		
Textural class		Clay	
Chemical properties			
PH	5.12	Strongly acidic	Havlin (1999)
OC (%)	1.18	Low	Landon (1991)
OM (%)	2.03	Low	Landon (1991)
TN (%)	0.1	Low	Havlin (1999)
Available P (mg/kg)	8.44	Low	Olsen (1994)
Exchangeable K (cmole/kg)	283.58	Optimum	Ethiosis (2014)
Available S (mg/kg)	14.16	Low	Ethiosis (2014)
Available B (mg/kg)	0.19	Very low	Ethiosis (2014)
Available Zn (mg/kg)	3.82	Optimum	Ethiosis (2014)
Available Fe (mg/kg)	148.02	Optimum	Ethiosis (2014)
Available Mn (mg/kg)	341.87	Optimum	Ethiosis (2014)
Available Cu (mg/kg)	1.21	Optimum	Ethiosis (2014)
Exchangable Mg (mg/kg)	171.22	High	Ethiosis (2014)
Exchangable Ca (cmole/kg)	819.02	High	Ethiosis (2014)
CEC (cmole/kg)	7.75	Low	Landon (1991)

to 25 and 25 to 40 cmol·kg^{-1} are rated as low, medium and high, respectively. Based on these ratings, the cation exchange capacity (7.75 cmol·kg^{-1}) before planting of the experimental field was in the low range. Exchangeable K (283.58 cmole/kg) was in the Optimum range, available S (14.16 mg/Kg) was in the low range, available B (0.19 mg/Kg) was in the very low range, available Zn (3.82 mg/Kg) was in the optimum range, available Fe (148.02 mg/Kg) was in the optimum range, available Mn (341.87 mg/Kg) was in the optimum range, available Cu (1.21 mg/kg)was in the optimum range, exchangeable Mg (171.22 mg/Kg) and exchangeable Ca (819.02 cmole/Kg) were in the high range, all are according to [27].

Generally the soil analysis result showed that, the soil is nutrient deficient to support the potential crop production. This may be associated with poor farm management practices and continuous cropping with little or no fertilizers input which resulted in a decline in soil fertility. It may be because of this that growth, yield and yield components of tef responded to supplied NPSB and K fertilizers in the present experiment.

3.2. Phenological Responses

3.2.1. Days to Panicle Emergence

Days to panicle emergence were highly significantly ($p < 0.001$) influenced by NPSB rates, however, K and its interaction with NPSB did not affect days to panicle emergence. Days to panicle emergence became quick with increasing rates of NPSB. The late (41) and prior (38) days to show panicle emergence was recorded from 25 Kg/ha and 100 kg/ha NPSB, respectively (Table 3). The earlier flower formation due to NPSB application over the unfertilized plots might be due to sufficient supply and uptake of N, P, S and B nutrients of which P has a leading role for flowering initiation, and B for endorsing of pollen growth and development and in turn improved days to heading. In agreement to present finding, different authors also reported that the application of balanced NPSB on

Table 3. Phenological responses.

	Days to panicle emergence	Days to maturity
NPSB		
0	39	72
50	38	74
100	38	73
200	39	77
KCl		
0	40	75
25	41	76
50	39	74
100	39	73

tef as in [36] and NPS on wheat as in [37] at higher rates helped an early flower beginning compared to unfertilized plots due to the uptake of other nutrients, enhanced growth and development, increase cytokinins synthesis and supply of photosynthates for flower formation. As in [38] further indicated that lower rate of nutrient delayed panicle emergence of tef due to longer time required to establish, grow and complete the vegetative growth.

3.2.2. Days to Maturity

Analysis of variance noted that days to maturity depicted significant difference ($p < 0.05$) due to application of NPSB; and the effect of K and interaction of both fertilizer did not result significant differences. Though variation among maturity days due to NPSB rates was narrow, delayance to reach maturity stage was recorded with increasing rates of NPSB. This is also supported by significant and positive correlation between days to maturity with NPSB. The maximum (77.00) and minimum (72.00) days to reach physiological maturity stage was observed from 200 kg/ha NPSB and unfertilized plot, respectively (**Table 3**). This might be attributed to greater assimilates partitioning from vegetative parts to the grains parts. This is supported by the findings of Aderaas in [36] who reported that application of NPS (64 + 57 + 10.5) and NPSB (64:72:13.4:1.42) delayed tef maturity than recommended blanket (64:46 NP) + unfertilized plot. Increased rates of combined application recommended NPS (40:60:0) + 5 t/ha FYM significantly lateness of tef maturity time (DZ-Cr-387) than control, recommended and 50% recommended + 2.5 t/ha FYM.

3.2.3. Response of Tef on Growth Components

Plant height

Different types of NPSB and K fertilizer had highly significant effects on the plant height (**Table 3**). The effect of K and interaction with NPSB fertilizer show significant differences at ($P < 0.0001$). The highest mean plant height was obtained from plots supplied with treatment NPSB (200 Kg/ha) (80.07 cm) which was significantly different from the other treatments, except NPSB (100 Kg/ha) (**Table 4**). The lowest plant height (78.18 cm) was recorded from the treatment NPSB (0 Kg/ha) (control), which was significantly inferior to all other treatments.. The reasons for the increased plant height under different NPSB and K fertilizer types could be due to the increased vegetative growth with applied N. In line with this, as in [39] obtained increased plant height of wheat fertilized with N. Similarly, as in [40] reported that applied N at different rates resulted in increased vegetative growth period of maize that increases photosynthetic assimilate production and its partitioning to stems that might have favorable impacts on heights of maize. On the other hands, increase in plant height due to application of NPSB might be attributed to more availability of nutrients due to increased levels of N, P, S and B, which exerted beneficial effect on vegetative growth of plant. Increase in plant height with supplied N and P levels has also been observed by [41]. This may be due to increased root growth, which strengthened the stem against lodging during prolonged vegetative growth. Furthermore, as [42] and [43] reported that marked increase in plant height of maize due to combined application of NP fertilizers.

Panicle length

The data showed that significant difference ($p < 0.0001$) on panicle length of tef due to application of NPSB while the application of K and interactions of both fertilizer not significantly different. The highest (32.83 cm) and the lowest (29.30 cm) panicle length were attained at 200 and 0 kg/ha NPSB rates, respectively (**Table 4**). Generally, the data revealed that panicle length had shown an increasing trend with NPSB.

Number of tillers plant^{-1}

Analysis of variance on tiller number plant^{-1} revealed the existence of highly significant difference among the combined application of NPSB and K fertilizers (**Table 3**). The effect of K and interaction with NPSB fertilizer show significant differences at ($P < 0.0001$). Maximum mean number of tillers plant^{-1} was obtained from the treatment NPSB (200 Kg/ha) and it was significantly at par with Control treatments (**Table 4**). The lowest tiller number per plant (16.58) was recorded from the control treatment.

This study is supported by Tabar [44] where application of N and P fertilizers found to favor tillering in rice. As in [45] also reported an increased number of fertile tillers, total biomass and straw yield of barley due to addition of P.

Culm length plant^{-1}

Application of different types of NPSB and K fertilizers significantly increased culm length (**Table 4**). The effect of K and interaction with NPSB fertilizer did not result significant differences. The highest culm length (56.55 cm) was recorded

Table 4. Response of tef on growth components.

Treatments	Plant height (cm)	Panicle length (cm)	Culm length (cm)	No of total tillers/plant	No of fertile tillers/plant	Main panicle seed weight(g)
NPSB						
0	78.18^{c}	29.54^{d}	54.26^{c}	16.58^{c}	8.86^{b}	1.15^{d}
50	83.05^{b}	30.61^{c}	55.95^{b}	18.73^{b}	9.43^{a}	1.18^{c}
100	84.43^{a}	32.31^{b}	56.42^{ab}	18.57^{b}	9.44^{a}	1.20^{b}
200	85.07^{a}	32.83^{a}	56.55^{a}	20.07^{a}	9.59^{a}	1.23^{a}
KCl						
0	80.39^{b}	30.98^{b}	55.10^{c}	18.50^{a}	9.27^{a}	1.16^{c}
25	82.96^{a}	31.29^{ab}	55.73^{b}	18.80^{a}	9.39^{a}	1.19^{b}
50	83.67^{a}	31.44^{ab}	55.74^{b}	18.31^{a}	9.26^{a}	1.21^{a}
100	83.72^{a}	31.57^{a}	56.61^{a}	18.33^{a}	9.42^{a}	1.20^{ab}
LSD (0.05)	0.901	0.489	0.530	0.676	0.218	0.008
CV (%)	1.31	1.87	1.14	4.39	2.81	0.81

from the application of treatment NPSB (200 Kg/ha). These treatments were significantly higher over the control. These results are similar with the findings as in [46] who reported maximum NP fertilizer utilization recorded the highest yield effects due to maximum accumulation of photosynthates.

Main panicle seed weight

Analysis of data pertaining main panicle seed weight of tef revealed that it was significantly affected due to K and NPSB fertilizer application, and interaction of both fertilizers are significantly different. Highest main panicle seed weight (1.23 g) of tef was recorded from 200 kg/ha NPSB fertilizer (Table 4). This might be due to the effect of fertilizer in maintaining cell turgidity and efficient translocation of assimilates to sinks by influencing electron transport in the transport chain of crops [47]. This result is in agreement with that of Almodares *et al.* [48], who found that application of fertilizer significantly altered panicle dry weight of sorghum Patil [49] also noted that under high fertilizer levels, starch is efficiently moved from sites of production to storage organs.

1000-grains weight

The data given in Table 4 showed that there were highly significant ($P < 0.01$) variations in fertilized and nonfertilized treatments for 1000-grain weight. Maximum 1000 grain weight (4.75 g) was obtained from plots treated with K at-100 kg ha-1. However, the minimum (4.05 g) 1000-grain weight was obtained from the control treatment (Table 5). All the other treatments fall in between these treatments. The relatively heavier seed weight in NPSB and K treated plots was obtained possibly due to increased assimilates production and photosynthesis efficiency at the grain filling stage of the plant because of improved plant mineral nutrition. Furthermore, it may be due to greater contribution of NPSB

Table 5. Response of tef on yield and yield components.

Treatments	Biological yield (t/ha)	Grain yield (t/ha)	Thousand seed weight (g)	Straw yield (t/ha)	Harvest index (%)	Lodging percentage (%)
NPSB						
0	5.76^{d}	1.71^{d}	0.28^{b}	4.05^{d}	29.75^{c}	28.25^{b}
50	6.53^{b}	2.02^{b}	0.29^{b}	4.51^{c}	30.89^{b}	30.50^{a}
100	6.41^{c}	2.16^{a}	0.29^{b}	4.25^{b}	33.93^{a}	30.17^{a}
200	6.67^{a}	1.98^{c}	0.30^{a}	4.68^{a}	29.74^{c}	30.42^{a}
KCl						
0	6.37^{c}	1.96^{c}	0.27^{c}	4.41^{b}	30.66^{b}	29.42
25	6.09^{c}	1.94^{bc}	0.28^{b}	4.16^{c}	31.93^{a}	29.67
50	6.10^{a}	1.92^{b}	0.29^{a}	4.18^{c}	31.54^{a}	30.08
100	6.80^{b}	2.06^{a}	0.29^{a}	4.75^{a}	30.18^{b}	30.17
LSD (0.05)	0.107	0.028	0.107	0.0003	0.666	1.157
CV (%)	2.04	1.72	2.94	0.120	2.57	4.66

and K by producing healthy grains which have well filled and bigger grains than thecontrol treatments. These results are similar with the findings as in [50] who reported improved seed weight due to combined application of NP fertilizers on maize.

3.2.4. Response of Tef on Yield and Yield Components

Grain yield

The fertilizer treatments significantly affected the grain yield of tef (**Table 5**). The yield was highest in the NPSB (100 Kg/ha) treatment. The effect of K and interaction with NPSB fertilizer show significant differences at ($P < 0.0001$). In the (control), the yields of tef was significantly lower than those other treatments. The increased grain yield due to applied NPSB and K might be attributed to low nutrient contents of study site (**Table 2**). Thus, the availability of these nutrients enables the plant to develop more extensive root system to extract water and nutrients, from more depth. This could enhance the plants to produce more assimilates, which was reflected in higher biomass [51]. Furthermore, the increases in yield due to P fertilizer may be attributed to the activation of metabolic process, where its role in building phospholipids and nucleic acid is known. This result is in agreement with the findings as in [52] who reported that application of N and P fertilizers increase grain yield of wheat.

Biological yield

Application of different types of NPSB and K fertilizer had highly significant effects on the biological yield of tef (**Table 5**). The effect of K and interaction with NPSB fertilizer show significant differences at ($P < 0.0001$).Highest biological yield of tef (6.80 $t \cdot ha^{-1}$) was obtained from treatment K (100 Kg/ha).The lowest biological yield (5.76 $t \cdot ha^{-1}$) was recorded from the control, which was significantly inferior to all other treatments. Greater plant height, yield and yield components might have contributed to the differences observed in biological yield among the different types of NPSB and K application. These results are in confirmation with the findings as in [53] and [54] who recorded maximum biological yield by the application of optimum N and P fertilizer rates when compared to the treatments receiving no N and P fertilizers.

Straw yield

The main effects of balanced NPSB and K fertilizer application significantly influenced straw yield of tef. The interaction effect of NPSB and K affect this parameter. The highest (4.75 t/ha) and lowest (4.05 t/ha) straw yield were recorded from 100 kg/ha K and unfertilized plots, respectively (**Table 5**). The research findings of [55] [56] and [57] on NP, indicated significant effects of mentioned nutrients on straw yield of cereals such as tef and rice due to their effects on organization of cell wall proteins, pectins, precursors during plant growth and development and high rate of net photosynthetic assimilation.

Lodging percentage

Lodging percentage was very highly significantly ($p < 0.0001$) influenced by the applied NPSB but K and interaction effects of both fertilizers are non significant. The maximum result was recorded from 50 kg/ha NPSB (30.50%) and the minimum was recorded from 0 kg/ha NPSB (28.25%) (**Table 5**). This might be associated to that high doses of NPSB fertilization promote crop vigourisity as a result it accelerate lodging percentage due to weak stem and high shoot to root ratio, however, low lodging percentage might be due to the stunted growth of tef caused by insufficient nutrition. This result agrees with [58] [59] and [60], who confirmed that abundant supply of nutrients in the soil leads to increase in the number of panicles and grains per panicle which can contribute to the process of lodging. Moreover, the findings of Markos [61] on NPS demonstrated that lodging percentage of tef increased with increasing rate of NPS. Overall, the result indicated that there was relatively low lodging percentage. This is attributed to shorter plant height variety (lower tendency to lodging), types of lodging (Permanent type of Bend lodging) [62] and lower seed rate per hectare (10 kg/ha) [63].

Harvest index

Harvest index was influenced significantly by different NPSB and K fertilizers treatments (**Table 4**). The highest harvest index (33.93) was recorded in NPSB (100 Kg/ha). The lowest harvest index (29.75) was recorded from the control treatment (**Table 5**). The physiological ability of a crop plant to convert proportion of dry matter into economic yield is measured in terms of harvest index. The results indicated that adequate supply of NPSB and K fertilizers in combination enhanced dry matter partitioning in favor of grain showing a greater harvest index. This is illustrated by the lower harvest indices observed under the treatments that received no NPSB and K treatments. These results corroborate the findings as in [64], who reported similar results.

3.3. Partial Budget Analysis

The result shown that the maximum net revenue were recorded from 100 kg/ha NPSB (57,738.70 Birr) and 50 kg/ha KCl (56,868.50 Birr), whereas minimum benefit recorded from 0 kg/ha NPSB (45,591 Birr) and 100 kg/ha KCl (48,190.50 Birr). The highest net benefit achieved from 100 kg/ha NPSB and 50 kg/ha KCl has 26.64 and 18% advantage over 0 kg/ha NPSB and 100 kg/ha KCl. Regarding marginal rate of return (MRR), the highest result (1542.29%) was recorded from 100 kg/ha NPSB and 50 kg/ha KCl (725.65%).

4. Conclusion

In this study it was found that, the combined application of NPSB and K fertilizers had a significant effect on growth, yield and yield components of tef. Among the treatments studied, NPSB (100 Kg/ha) and K (50 Kg/ha) gave greater grain yield. Furthermore, this treatment enhanced growth and yield related parameters compared to the control treatment. Thus, it is possible to recommend each to attain greater grain yield of tef in the study area. However, it is advisable to undertake further research across soil type, years and locations to draw sound recommendation on a wider scale.

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Conflicts of Interest

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

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