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Response of Teff [*Eragrostis tef* (Zucc.) Trotter] Varieties to Blended NPS Fertilizer Rates on Yield and Yield Components in Hidhabu Abote District, North Showa

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Abstract: Teff is one of the major crops grown at Hidhabu Abote district, North Showa Oromia National Regional State; however, its productivity is low due to lack of improved varieties and poor soil fertility as result of intensive soil erosion and long history of cultivation. Therefore, a field experiment was carried out on a farmer's field in the district, during the 2019 cropping season to assess the effect of NPS fertilizer rates on productivity of teff varieties and to determine the economically feasible NPS fertilizers rates for teff varieties production. The treatments consisted of factorial combinations of five levels of NPS (0, 50, 100, 150 and 200 kg ha^{-1}) fertilizer rates and four teff varieties (Nigus, Kora, Dagem and Local). The experiment was laid out in a randomized complete block design with three replications. The mean number of total tillers and productive tillers, straw yield and lodging index were highly significantly (P<0.01) affected by main effect of both varieties and NPS fertilizer rates. Dry biomass and grain yield were significantly (P<0.01) affected by the main effect of varieties and NPS fertilizer rates. Whereas harvest index and thousand seed weight were significant (P<0.01) affected only by main effect of varieties. Significantly higher total tillers (1478 plant m^{-2}) and productive tillers (1393 plant m^{-2}) were recorded from Dagem variety with application of 150 kg NPS ha^{-1} fertilizer rate. Higher dry biomass (10280 kg ha^{-1}) and straw yield (8354 kgha^{-1}) were obtained from Kora varieties. Significantly higher grain yield (2367 kg ha^{-1}), dry biomass (11577 kg ha^{-1}) and straw yield (9210 kg ha^{-1}) were obtained from application of 150 kg NPS ha^{-1} fertilizer rate. Highest lodging index (80%) was recorded from application 200 kg NPS ha^{-1} fertilizer rate. The yield and yield components of teff were strong significant and positive correlation of grain yield with all parameters except with lodging index. The application of 150 kg NPS ha^{-1} fertilizer gave higher net benefit of 76991 ETB ha^{-1} with the marginal rate of return of 750%. Therefore, application of 150 kg NPS ha^{-1} fertilizer could be recommended for production of teff in the study area and other areas with similar agro-ecological conditions.

Key words: NPS · Teff · Yield

INTRODUCTION

Teff [*Eragrostis tef* (Zucc.) Trotter] is a small cereal grain indigenous to Ethiopia and it has been recognized that the country is the center of origin and diversity of teff [1]. Teff has the largest value in terms of both production and consumption in Ethiopia. The value of the commercial surplus of teff is second to coffee [2]. Moreover, the economic contribution of teff indicates that real teff output on average accounted for 6.1% of the real GDP, while growth in real teff output accounted for 6.4% of the total growth in real GDP i.e., 0.67% of the 10.7% growth in real GDP [3]. Teff is commonly grown in the altitude ranging from 1800 to 2100 meters above sea level, with the major producing areas being Amhara, Oromia, Tigray and South Nations, Nationalities and People SNNP regions. It is a versatile cereal crop with respect to adaptation for the diverse agro-climatic and soil conditions [4].

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In Ethiopia, teff is the single dominant cereal that occupied 3.08 million hectares and the production is about 5.4 million tons per year [5]. Teff production in Oromia National Regional State total land area of 1, 431, 869.73ha with total production of 25, 628, 688.88qt with productivity 1.79t ha^{-1} [5] while in North Showa, Teff production with total Area of 107, 256 ha, total production 1, 876, 980 qt and with productivity 1.75 t ha^{-1}. Teff is among major crops grown and used for home consumption and marketing in Hidhabu Abote District of North Showa Zone in Oromia Region. The total cultivated area of the district is 32, 917 ha out of which teff covers 10, 826 ha. The average yield of teff is 1750 kg ha^{-1} in that particular area and this is almost equals to the average national yield (1756 kg ha^{-1}) of teff [5]. Teff is primarily grown to prepare '*injera',* porridge and some native alcohols drinks [6]. Nutritionally, teff grain is gluten-free, rich in phosphorous, copper, magnesium, aluminum and thiamine and is an excellent source of protein, amino acids and carbohydrates. Teff is higher in calcium, iron and zinc content than corn, wheat, or rice [7]. International demand for teff is also increasing due to its high nutritional value and its potential as water efficient fodder for livestock [8].

More than six million households' life depend on the production of teff covering the largest agricultural area of the country than any other types of grain, but its production and productivity is still very low due to traditional agronomic practices, nutrient deficiencies and susceptibility of the crop to lodging [9]. However, the amount of production is not as much as its production coverage and value [10]. The low teff crop productivity could be due to a complex interaction among the environments, lack of appropriate management practices, biotic and a biotic stress. Of these, soil fertility problem is one of the major causes of temporal and spatial yield variability [11]. Following soil fertility map made over 150 districts EthioSIS [12] reported that Ethiopian soil lacks about seven nutrients; N, P, K, S, Cu, Zn and B. Of which, the study area particularly lacks Sulphur. Although nitrogen and phosphorus nutrients are among the major teff yield limiting soil nutrients, the unbalanced and sub-optimal fertilization of Ethiopian soils by applications of only DAP and Urea (N and P containing fertilizers) for a long period of time has led to severe nutrient mining of the agricultural soils, particularly when the entire crop biomass (grain and stover) are removed from the land [13]. According to Yonas [14] lack of appropriate macro or micro-nutrients in fertilizer blends is one of the national problems which act as the major constraint to crop productivity. Hence, the continuous use of DAP and Urea should be supplemented with the application of additional compound fertilizers containing all the required and deficient in the soil macro and micro-nutrients.

The most important short coming in teff production is its inherent low productivities of local variety. The local teff has low yield potential as compared to improved teff varieties. Hence, the major factor which affects the yield of teff is lack of improved variety and different varieties are generally expected to respond differently to fertilizer applications. The local teff variety that is most often cultivated in the study area is known as '*Kacha'*. It has low yield potential. However, the genetic improvement of the crop has resulted in the development of varieties that could yield as high as 4 tons ha^{-1} [15]. Such a high yielding varieties have been released by Debre Zeit Agricultural Research Center and is being aggressively disseminated in different parts of Ethiopia. Teff varieties named 'Nigus, 'Kora' and 'Dagem' are released for optimum rainfall areas among twenty-four improved teff varieties so far been released by Debre Zeit Agricultural Research Center (DZARC) and these varieties needed to be disseminated in the study area based on their adaptation.

Farmers in Central Ethiopia use 100 kg ha^{-1} of DAP (18 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}) and 100 kg ha^{-1} Urea (46 kg N) alone for teff production on *Vertisol* [16]. Those blanket recommendation brought generally, an increase in yield of improved varieties ranging from 1700 to 2200 kg ha^{-1} [17]. However, the recommendation does not work for all production aspects of various soil types of different regions. Moreover, to realize optimum yield of the crop, appropriate fertilizer rates have to be used since this could vary according to soil type and weather condition of area. The response of teff varieties to fertilizers depends on type of fertilizers, rates applied, time and method of application. Higher yield responses to recommended rates of fertilizers are obtained from released varieties than local ones. However, all growth parameter of both varieties is highly influenced by fertilizer application [18]. Thus, author also reported that it was possible to increase yield by more than two folded using improved varieties and their respective recommendation fertilizer rates.

Application of balanced fertilizers could be the basis to produce more crop output from existing land under cultivation and nutrient needs of crops according to their physiological requirements and expected yields [19]. However, the fertilizer type and rates vary according to soil type, weather conditions, varieties, agronomic practices. Even though improved teff varieties like Nigus, Dagem and Kora are not cultivated by the use of NPS fertilizers application except the blanket recommendation of DAP and Urea fertilizers which give low yields as compared to yield potential of the crops. However, higher yield responses to recommended rates of fertilizers are obtained from released varieties than local ones in many parts of the country. Lulu [18] also reported that it is possible to increase yield by more than two folded using improved varieties with their respective recommendation fertilizer rates. Hence, in the study area main research gap for low productivities of teff lack of recommended fertilizer rate and lack of information on response of different varieties. Moreover, currently there is little or no information of site-specific recommendation of NPS fertilizer for teff production in the study area especially for recently released improved teff varieties. Therefore, the objective was to assess the effect of NPS fertilizer rates on yield and yield components of teff varieties and to determine the economically optimum NPS fertilizer rate for teff production.

MATERIALS AND METHODS

Description of the Study Area: The experiment was conducted on farmer's field in Mojo *Kebele* Hidhabu Abote District, North Showa Zone, Oromia Regional National State during the 2019 cropping season. It is located at 142 km from Addis Ababa on the way to Gojem and about 43 km from zonal town of Fitche. Geographically, the District is situated at latitude of 9.81°47' N, longitude of 38°27' E and altitude of 1850 meters above sea level.

The study area is characterized by a bimodal rainfall pattern with the main rainy season 'Ganna' extending from July to September and the short season 'Arfasa' extends from March to May. The average annual rainfall and mean annual minimum and maximum temperatures of the area based on last 10 years (2009-2019) records were 1014 mm and 8.57 and 20.87°C respectively [20]. The total rainfall of the study area during the growing season was 915 mm which was suitable for maximum teff production throughout the growth stages and the mean minimum and maximum temperatures were 11 and 20.5°C, respectively [20].

Major soil type of the study area is *Nitisols*. The soil is clay textured with pH of 5.56, low content of N (0.15%), organic matter (1.42%), available P (4.36 ppm) and moderate CEC (21.67 meq/100 g soil). The experimental site was under wheat cultivation during the previous growing season.

Major crops grown in the area are teff, wheat, sorghum, faba bean, lentil and field pea. The area has been under cultivation for long periods of time and so are the crops. Almost all farmers practice crop-dominated mixed crop-livestock farming system in every fragmented plots of land that allow the land no time to rest. The land is continuously exploited and poor in fertility and particularly very low in organic matter as crop residues are not left in the fields after harvest basically for straw utilization [21].

Experimental Treatments and Design: The treatments were consisting of three teff varieties 'Nigus' (DZ-Cr-429), Dagem (DZ-Cr-438(RIL-91A) and Kora (DZ-Cr-438 RIL133B) which were released from Debre Zeit Agricultural Research Center in 2016, 2015 and 2014, respectively and Local cultivar as check were used for the experiment [22] and five rates of NPS (0, 50, 100, 150 and 200 kg NPS ha^{-1}). NPS (19% N, 38% P_2O_5 and 7% S) and Urea (46% N) fertilizers were used as source of nutrient elements. The experiments were laid out as a randomized complete block design in a factorial arrangement with three replications.

Experimental Procedure: Field was ploughed and prepared according to Farmers practices before planting. In accordance with the specifications of the design, a field layout was prepared. A plot size of 2 m x2 m (4 m^2) with 20 cm row spacing and a total of 10 rows were used. Each treatment was assigned randomly to the experimental plots within a block. Rows were made manually before sowing and the whole amount of NPS fertilizer rates was applied at sowing time as basal application to each plots and nitrogen at the specified rates were applied in two splits in the form of Urea 100kg (½ of the Urea at sowing and the remaining ½ was applied at tillering stage). Teff varieties 'Nigus' Dagem, Kora and local variety was manually drilled uniformly at the rate of 10 kg ha^{-1} in rows at a depth of about 3 cm on 8 of July 2019. Half of urea fertilizer was applied in the soil as basal application (5 cm) away from the seed planting) by making a shallow furrow along the teff row to avoid the seed contact and then covering with soil.

The outermost two rows from each side of a plot and 0.1 m on both ends of each row were considered as border and not included for data recording. Thus, the net harvestable area was 1.6m x 1.8 m (2.88 m^2). Harvesting was done on 8 November 2019 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 for three days until constant weight. The total dry matter was weighed by using field balance. Threshing and winnowing were done manually on a mat. After threshing, the grain yield was weighed using sensitive digital balance. All other cultural practices were uniformly applied to each of the plots as per the recommendations for the test location.

Soil Sampling and Analysis: Soil samples were collected randomly in a Zig-Zag pattern from the entire experimental field using an auger to the depth of 0-20 cm before sowing from 11 spot and composited into one sample. The collected soil sample was prepared following standard procedures under the shade, grounded using mortar and pestle, sieved through a 2 mm sieve. The sieved soil was stored in a clean plastic container for subsequent physical and chemical analysis. The soil analysis was done for soil textural class, soil pH, organic carbon, total N, available P, available S and CEC at Horticoop Ethiopia (Horticulture) PLC Soil Laboratory.

Soil textural class was determined by Bouyoucos Hydrometer Method [23]. Soil pH was determined in 1:2.5 soils to water ratio using a glass electrode attached to a digital pH meter [24]. Organic carbon was determined by wet digestion method [24] then the organic matter (%) was calculated by multiplying the OC% by factor 1.724. Total N (%) was determined using the Kjeldhal method [25]. Available P (mg/kg (ppm) was determined by Bray and Kurtz method [26]. Available S (mg/kg (ppm) and exchangeable bases (potassium, magnesium, sodium and calcium) were determined by Melich-3 methods [27]. For Cation Exchange Capacity of the soil (Meq/100 g soil), the sample was first leached using 1M ammonium acetate, washed with ethanol and the adsorbed ammonium replaced by sodium (Na). Then, the CEC was determined titrimetrically by distillation of ammonia that was displaced by Na [28].

Data Collected

Yield and Yield Components

Total Tillers: Both effective and non-effective tillers were determined at physiological maturity by counting all the tillers in 0.5 m length from two rows of net plot area and then converted to m^2.

Dry Biomass Yield: Was weighted the harvested crop from the net plot area after sun drying for three days 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 grain yield of each treatment was adjusted to the standard moisture level by computing the conversion factor for each treatment to get the adjusted yield using the following formula [29].

$$\text{Conversion factor (C.F)} = \frac{(100 - y)}{(100 - x)}$$

Thousand Seed Weight: Was determined by carefully counting 1000 small grains from the bulk of threshed yield and weighing them using a sensitive balance.

Straw Yield: Was measured after threshing and measuring the grain yield by subtracting the grain yield from dry biomass yield.

Harvest Index: Was calculated by dividing grain yield by the total aboveground dry biomass yield and multiplied by 100.

Lodging Index: Was assessed just before the time of harvest by visual observation based on the scale of 1-5. Where 1 =0-15°, indicates no lodging, 2 =15-30°, indicates 25% lodging, 3 =30-45°, indicates 50% lodging, 4 =45-60°, indicates 75% lodging and 5 =60-90°, indicates 100% lodging [30]. The scale was determined by the angle of inclination of the main stem from the vertical line to the base of the stem by visual observation. Each plot was divided based on the displacement of the aerial stem in to all scales by visual observation. Each scale was multiplied by the corresponding percent given for each scale and average of the scales represents the lodging percentage of that plot. Data recorded on lodging percentage were transformed by arcsine transformation method to normalize the error mean squared as described by Gomez and Gomez [31].

Data Analysis: The collected data were subjected to analysis of variance (ANOVA) using GenStat release 18th ed. software [32]. Means of significant treatment effects were separated using the Fishers' protected Least Significant Difference (LSD) test at 5% level of significance [33].

Economic Analysis: Partial budget analysis was done using procedure as described by CIMMYT [34]. Labor costs involved for application of NPS and N fertilizer rates were recorded and used for analysis. The current price of grain yield of teff were valued at an average open market price at Ejere town for Kora, Dagim and Nigus varieties were 35.0 ETB kg^{-1} and Local cultivar was 26.0 ETB kg^{-1} as well as the price of straw yield were 0.5

ETB kg^{-1}. The yield was down adjusted at 10 percent to reflect the actual farmers condition. The price of NPS fertilizer was 14.50ETB kg^{-1} and the cost of seed teff varieties were 45.0 ETB kg^{-1}, except local variety was 28.0 ETB kg^{-1}. The costs of other inputs and production practices such as labour cost for land preparation, planting, weeding, harvesting and threshing were considered the same for all treatments or plots.

RESULTS AND DISCUSSION

Soil Physical and Chemical Properties: The results of the pre-sowing composite soil sample analyses are indicated in Table 1. The soil textural class of experimental site was 66% clay, 26% silt and 8% sand (Table 1). The texture of the soil was clay [35]. The pH of the soil was 5.56 (Table 1), which was moderately acidic and, in most cases, sub-optimal for the production of most field crops [36]. Teff is normally grown on soils of neutral pH, but it has been observed that it tolerates soil acidities below pH 5.This value falls in the pH range that is conducive for teff production [15].

The organic carbon content of the experimental field was low (1.42%) (Table 1) [36]. This indicates the low potential of the soil to supply nitrogen to plants through mineralization of organic carbon. The low amount of soil organic carbon might be due to complete removal of crop residues and less aeration due to soil compaction of sub-soils. Most cultivated soils of Ethiopia are poor in organic matter content due to low amount of organic materials applied to the soil and complete removal of biomass from the field.

The total nitrogen was 0.15% (Table 1) which was low [36]. The low nitrogen content might be due to the loss of nitrogen from the soil system easily through leaching, denitrification, volatilization, crop removal, soil erosion and runoff as the land is continuously cultivated. The available P of the experimental soil content was found 4.36 ppm which is considered as low P according to Bray and Kurtz [26] (Table 1). The available sulfur indicated that the experimental soil had value of 19.08 ppm of available sulfur which is rated low [37].

Number of Total Tillers: The interaction effects of varieties and NPS fertilizer rate were significant ($P<0.05$) on number of total tillers. Moreover, the main effect of varieties and NPS fertilizer rate was highly significant ($P<0.01$) on number of total tillers (Table 2). The highest number of total tillers (1478 plant m^{-2}) was obtained from Dagem varieties with combination of 150 kg NPS ha^{-1} fertilizer rates, while the lowest number of total tillers (792 plant m^{-2}) was obtained from Local cultivars with combination of un-fertilized plot (Table 2). This result is in agreement with Brhan [38] 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}) brought significant increase in total tillers (15 tillers per plant) of teff as compared to 5 tillers per plant of unfertilized plot. Similarly, Seifu [39] stated that highest number of total tillers (1295 plant m^{-2}) was obtained with the application of blended fertilizer 150 kg NPSB ha^{-1} with Kuncho variety, while the lowest number of total tillers (890 plant m^{-2}) was obtained from the unfertilized plots.

In contrary, Shiferaw [40] reported no significant difference on total tiller number of teff as the rate of P_2O_5 was increased from zero to 46 kg ha^{-1} Kuncho variety. In barley, Wakene *et al.* [41] also reported no significant differences between application of 46 and 69 P_2O_5 kg ha^{-1} in total tillers. Similarly, Esayas [42] who reported no significant differences in the numbers of total tillers per plant among different blended fertilizers NPSZnB in durum wheat.

This is because of the fact that the higher rates of NPS might result rapid conversion of synthesized carbohydrates into protein and consequently the increase in number and size of growing cells which ultimately cause an increased number of tillers keeping the genetic difference of teff genotypes as it is. The improvement in total number of tillers with NPS application might be due to the role of P found in NPS in developing radical and seminal roots during seedling establishment [43].

Number of Productive Tillers: The main effect of varieties and NPS fertilizer rate and their interaction effect were highly significant ($P<0.01$) on number of productive tillers (Table 3). The highest number of productive tillers (1393 plant m^{-2}) was obtained from Dagem varieties with the application of 150 kg NPS ha^{-1} fertilizer which was statistically par with Dagem varieties with application of 200 kg NPS ha^{-1} (1312 plant m^{-2}) and Kora by application of 150 kg NPS ha^{-1}, (1300) while the lowest number of productive tillers (643 plant m^{-2}) was obtained from local cultivar with un-fertilized plots (Table 3). The highest number of productive tillers might be due to the genotype characteristic of the varieties and sufficient amount of growth and development of plants owing to the essential elements under NPS fertilizer condition. The maximum number of productive tillers may be due to P is the main element involved in energy transfer for cellular metabolism in addition to its structural role. Likewise, Seifu [39] reported that the highest number of productive tillers (1189 plant m^{-2}) was obtained with the application of

Table 1: Soil physical and chemical properties of the experimental site before sowing

Soil properties	Values	Ratings	References
A. Physical properties			
Clay (%)	66		
Silt (%)	26		
Sand (%)	8		
Textural class	Clay		Bouyoucos (1962)
B. Chemical Properties			
pH (1:2.5 H_2O)	5.56	Moderately acid	Tekalign (1991)
Organic carbon (%)	1.42	Low	Tekalign (1991)
Total N (%)	0.15	Low	Tekalign (1991)
Available P (ppm)	4.36	Low	Bray and Kurtz (1945)
CEC (meq/100 g soil)	21.67	Moderate	Landon (1991)
Available S(ppm)	19.08	Low	Ethio-SIS (2014)

Table 2: Means of total tillers of teff as affected by the interaction of varieties and NPS fertilizer rates

	NPS (kg ha^{-1}) fertilizer rates					
Varieties	0	50	100	150	200	Mean
Local	792^{j}	1088^{cdefgh}	1097^{cdefg}	1253^{bcde}	1100^{cdef}	1066^{d}
Kora	857^{ij}	995^{fghij}	1100^{cdef}	1407^{ab}	1298^{abc}	1131.3^{b}
Dagem	873^{ghij}	1048^{defghi}	1143^{cdef}	1478^{a}	1437^{ab}	1196^{a}
Nigus	870^{hij}	957^{fghij}	1040^{efghi}	1238^{bcde}	1265^{abcd}	1074^{c}
Mean	847.9^{e}	1022.1^{d}	1095^{c}	1344.2^{a} 1275^{b}		
	Varieties	NPS rates		Varieties X NPS rates		
LSD (5%)	53.81	60.16		120.32		
CV (%)	6.5					

Means in column and row followed by the same letters are not significantly different at 5% probability level

Table 3: Mean productive tillers of teff as affected by the interaction of varieties and NPS fertilizer rates

	NPS (kg ha^{-1}) fertilizer rates					
Varieties	0	50	100	150	200	Mean
Local	643^{k}	942^{fgh}	1002^{def}	1098^{bcd}	972^{efg}	931.3^{d}
Kora	750^{j}	883^{gh}	985^{ef}	1300^{a}	1147^{b}	1013.0^{b}
Dagem	770^{ij}	937^{fgh}	1047^{cde}	1393^{a}	1312^{a}	1091.7^{a}
Nigus	780^{hi}	860^{hi}	950^{efgh}	1142^{bc}	1115^{bc}	969.3^{c}
Mean	735.8^{e}	905.4^{d}	995.8^{c}	1233.3^{a} 1136.2^{b}		
	Varieties	NPS rates		Varieties X NPS rates		
LSD (5%)	44.33	49.56		99.13		
CV (%)	6.0					

Means in column and row followed by the same letters are not significantly different at 5% probability level

Table 4: Means of thousand kernels, dry biomass and harvest index of teff as influenced by the main effects of varieties and NPS fertilizer rates

Treatment	Thousand seed weight (g)	Dry biomass (kg ha^{-1})	Harvest index (%)
Varieties			
Local	0.2467^{b}	8410^{b}	20.67^{b}
Kora	0.2933^{ab}	10280^{a}	19.20^{b}
Dagem	0.3267^{a}	10190^{a}	21.14^{b}
Nigus	0.2733^{ab}	8542^{b}	23.85^{a}
LSD (5%)	0.4577	1245	2.177
NPS (kg ha^{-1})			
0	0.2333	4644^{c}	23.29
50	0.250	9013^{b}	20.73
100	0.3167	10292^{ab}	21.38
150	0.325	11577^{a}	20.53
200	0.300	11250^{a}	20.19
LSD (5%)	NS	1392	NS
CV (%)	21.7	18	13.9

where, NS= non-significant. Means in column followed by the same letters are not significantly different at 5% probability level blended fertilizer 150 kg NPSB ha^{-1} with Kuncho variety, while the lowest number of total tillers (761 plant m^{-2}) was obtained from the control plots. Similarly, Fayera *et al*. [44] found that the highest productive tillers of teff (26 tillers per plant) under the application of 200 kg ha^{-1} NPKSZnB blended (14 N, 21 P_2O_5, 15 K_2O, 6.5 S, 1.3 Zn and 0.5 B) + 23 kg N ha^{-1} fertilizer with Kuncho variety. In contrary, Alemu *et al*. [45] stated that number of productive tillers was not significantly influenced by the main effect of cultivars as well as by interaction effects of cultivars and P fertilizer rates.

Thousand Seed Weight: The main effect of varieties was significant (P<0.05) effect on thousand seed weight of teff but the main effect of NPS fertilizer rates and the interaction effect of the two factors were not significant (Table 4). The highest thousand seed weight of teff (0.3267 g) was obtained from Dagem variety and it was statistically at par with Kora and Nigus; while the lowest thousand seed weight of teff (0.2467 g) was obtained from local cultivar. Thousand seed weight is an important yield determining component and reported to be a genetic character that is influenced least by environmental factors [46]. Likewise, Leila and Ali [47] have shown either no improvement or reduced seed weight due to N fertilization even when yields increased. Zewdu *et al*. [48] also reported no significant response of thousand grains weight to application of N fertilizer in the highlands of Ethiopia. Also, Esayas [42] reported that blended fertilizer (NPS, NPSB, NPSZnB) application had no significance effect on thousand grain seed weight of wheat. In contrary, Alemu [45] reported that increase in thousand seed weight with increasing of NP fertilizer rates.

Dry Biomass Yield: The main effects of NPS fertilizer rates and varieties were significant (P<0.01; P<0.05) effect on dry biomass yield of teff, respectively, however the interaction effects of two factors was not significant (Table 4). The highest dry biomass yield (10280 kg ha^{-1}) was recorded from Kora variety which was statistically at par with Dagem varieties with mean dry biomass yields of 10190 kg ha^{-1}, while the lowest dry biomass yield (8410 kg ha^{-1}) was recorded from local cultivar which was statistically at par with Nigus with mean dry biomass yields of 8542 kg ha^{-1} (Table 4). This findings in agreement with result of Fenta [49] who reported that the highest biomass yield (1056.6g and 890.3 per plot) and the lowest biomass (701.5g followed by 492.9g per plot) was obtained from Kuncho and Jimma local cultivars respectively. Similarly, Natol *et al*. [50] who reported that the highest biomass was recorded from Magna (9.67 t/ha) followed by local check (8.50 t/ha), whereas the lowest biomass was recorded for Dz-cr-385 (2.63 t/ha).

The highest mean dry biomass yield (11577 kg ha^{-1}) was recorded from application of 150 kg NPS ha^{-1} fertilizer rates which was statistically at par with 200 kg NPS ha^{-1} fertilizer rates (11250 kg ha^{-1}), while the lowest dry biomass yield (4644 kg ha^{-1}) was recorded from un-fertilized plots (Table 4). The increase in dry biomass of teff due to high nutrients particularly N, P and S might be the plants ability to capture ample solar radiation, which may result in the corresponding increment of photosynthetic rate. The increase in dry biomass yield at the highest rates of NPS might have resulted from improved root growth and increased uptake of nutrients favoring better growth of the crop due to synergetic effect of the nutrients (NPS). Similarly, Fayera *et al*. [44] reported a significant increase in total dry biomass of teff (3720 kg ha^{-1}) as a result of application of 69 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1}. Similarly, Wakene *et al*. [41] stated that supply of P_2O_5 at rate of 69 kg ha^{-1} in wheat was found to be adequate to produce maximum aboveground dry biomass. Likewise, Seifu [39] reported that the highest total dry biomass yield (12387 kg ha^{-1}) was obtained from blended 150 kg NPSB ha^{-1} fertilizer application on Vertisols. Shiferaw [40] also indicated that dry biomass yield was significantly affected by application of blended fertilizer and NP.

Harvest Index: The main effect of varieties had a significant (P<0.01) effect on harvest index but the main effect of NPS fertilizer rate and the interaction of the two main factors were not significant (Table 4). The highest harvest index of 23.85% was recorded at Nigus variety while the lowest harvest index (19.2%) was recorded from Kora variety which was at par with Dagem and Local (Table 4). Harvest index indicates the balance between the productive parts of the plant and the reserves, which form the economic yield. High harvest index indicates the presence of good partitioning of biological yield to economical yield. This result was agreement with findings of Natol *et al*. [50] who reported that the highest harvest index was recorded from Tsedey (23%) while the lowest harvest index was recorded from Key Tena and Dz-01-1821 (16%). Moreover, it is also in agreement with the results of Seifu [39] who reported that the application of NPSB fertilizer in different rates was not shows significant effect on harvest index. In contrary, Kumela *et al*. [51] reported that the highest harvest index (34%) was recorded from the highest combination of 80/80 kg of N/P_2O_5 ha^{-1} on Kora teff varieties.

Table 5: Means of grain yield, straw yield and logging index of teff as influenced by the main effects of varieties and NPS fertilizer rates

Treatment	Grain yield (kg ha^{-1})	Straw yield (kgha^{-1})	Lodging index%
Varieties			
Local	1705[b]	6704[b]	45.47[a]
Kora	1926[ab]	8354[a]	40.33[ab]
Dagem	2108[a]	8081[a]	34.80[b]
Nigus	2028[a]	6514[b]	45.33[a]
LSD (5%)	258.949	1040.506	5.136
NPS (kg ha^{-1})			
0	1051[c]	3593[c]	11.75[e]
50	1853[b]	7160[b]	20.17[d]
100	2189[ab]	8103[ab]	31.25[c]
150	2367[a]	9210[a]	64.25[b]
200	2250[a]	9000[a]	80.00[a]
LSD (5%)	289.514	1163.321	5.743
CV (%)	18	19	16.7

Means in columns and rows followed by the same letters are not significantly different at 5% probability level

Grain Yield: The main effects of NPS fertilizer rates and varieties were significantly ($P<0.01$; $P<0.05$) affected grain yield of teff respectively, while interaction effect of the two factors was not significant (Table 5). The highest grain yield (2108 kg ha^{-1}) was recorded from Dagem varieties which was statistically par with Nigus (2028 kg ha^{-1}) and Kora (1926) varieties, while the lowest grain yield (1705 kg ha^{-1}) was recorded from local cultivar (Table 11). This is because of genotypic deferential in terms of yielding ability. As compared to other varieties Dagem is high yielding than local cultivar. This result was also in agreement with Yared *et al*. [52] who reported that Dagem variety gave superior grain yield (3734 kg ha^{-1}) than the local cultivar. Similarly, Natol *et al*. [50] who reported that the highest grain yield was recorded from Magna (2.03 t/ha) followed by Local and Tsedey (1.79 t/ha). An increase in the application of NPS fertilizer rate from control to 150 kg NPS ha^{-1} increased mean grain yield, however further increase to 200 kg NPS ha^{-1} showed a decreasing trend on grain yield of teff (Table 5). The highest grain yield (2367 kg ha^{-1}) of teff was obtained at the rate of 150 kg NPS ha^{-1} fertilizer application, while the lowest grain yield of 1051 kg ha^{-1} was recorded from non-treated (control) plot. However, the highest grain yield (2367 kg ha^{-1}) recorded at 150 kg NPS ha^{-1} fertilizer rate was at par with the yield obtained from 100 and 200 kg NPS ha^{-1} fertilizer rates (Table 5).

The highest grain yield at the high NPS rates might have resulted from improved root growth and increased uptake of nutrients and better growth favored due to synergetic effect of the nutrients which enhanced yield and yield components. Likewise, Bereket *et al.* [53] reported that increasing P rate from 46 to 69 kg P_2O_5 ha^{-1} increased grain yield of bread wheat by about 6.8%. Also, Jarvan *et al*. [54] reported that the addition of 100 kg N ha^{-1} with 10 kg S ha^{-1} to winter wheat gave yield of 5.88 t ha^{-1} while it gave 5.73 t ha^{-1} when 100 kg N ha^{-1} with 6 kg ha^{-1} S. On the other hand, Brhan [38] reported that treatments that received blended fertilizers (69 kg N ha^{-1} + 46 kg P_2O_5 + 22 kg S ha^{-1} + 0.3 kg Zn ha^{-1}) under row planting of teff is obtained 4155 kg ha^{-1} and increased 30% and 378% over treatments that receive Urea and DAP under row planting and control plots, respectively. In agreement with this study Seifu [39] reported that highest grain yield (3228 kg ha^{-1}) of teff was obtained at the highest rate of blended (150 kg NPSB ha^{-1}) fertilizer application.

Straw Yield: The main effects of varieties and NPS fertilizer rates were highly significant ($P<0.01$) on straw yield of teff. However, the interaction effects of the two factors on straw yield of teff were not significant (Table 5). The highest straw yield (8354kg ha^{-1}) was recorded from Kora varieties which was statistically at par with Dagem variety with mean straw yield of 8081 kg ha^{-1}, while the lowest straw yield (6514 kg ha^{-1}) was recorded from Nigus variety which was statistically at par with local cultivar with mean straw yield of 6704 kg ha^{-1} (Table 5). This is because of the genotype variability of the varieties. The highest straw yield (9210 kg ha^{-1}) was recorded from 150 kg NPS ha^{-1} fertilizer rates which was statistically at par with 200 kg NPS ha^{-1} (9000 kg ha^{-1}) and 100 kg NPS ha^{-1} (8103kg ha^{-1}) mean straw yield, while the lowest straw yield (3593 kg ha^{-1}) was recorded from control or un-fertilized plot (Table 9). The significant increase in straw yield in response to the highest rate of application NPS fertilizer might be attributed to the synergic roles of the nutrients in enhancing growth and

Table 6: Correlation of yield and yield component of teff due to varieties and NPS fertilizer rates

	PT	TTN	DBY	GY	STR	TSW	HI	LI
PT								
TTN	0.98***							
DBY	0.76***	0.74***						
GY	0.72***	0.68***	0.90***					
STR	0.74***	0.73***	0.99***	0.86***				
TSW	0.55***	0.54***	0.62***	0.60***	0.61***			
HI	0.28*	0.31*	0.40**	0.41**	0.51***	0.19ns		
LI	-0.65***	-0.68***	0.60***	-0.59**	-0.56***	-0.30*	-0.22ns	

where * and ** = significant at the 0.05 and 0.01 probability level, PT= productive tiller, TTN= total tiller number, DBY= dry biomass yield, GY= grain yield, STR= straw yield, TSW= thousand seed weight, HI= harvest index, LI= lodging index

Table 7: Economic feasibility of NPS fertilizer rates on teff production

NPS fertilizer rate (kg ha^{-1})	Grain yield (kg ha^{-1})	Adjusted Grain yield (kg ha^{-1})	Straw biomass (kg ha^{-1})	Gross grain field benefit (EB ha^{-1})	Gross straw benefit (EB ha^{-1})	Total field benefit (EB ha^{-1})	TCV (EB ha^{-1})	Net benefit (EB ha^{-1})	Value to cost ratio	MRR (%)
0	1051	946	3593	33107	1797	34903	0	34903		
50	1853	1668	7160	58370	3580	61950	725	61225	84.45	3631
100	2189	1970	8103	68954	4052	73005	1450	71555	49.35	1425
150	2367	2130	9210	74561	4605	79166	2175	76991	35.40	750
200	2250	2025	9000	70875	4500	75375	2900	72475D	24.99	

where, D = dominated treatments. ETB ha^{-1} = Ethiopian Birr per hectare; Market price of teff varieties (Kora, Dagim, and Nigus = 35.0, local = 26.0 ETB kg^{-1}); Market price of straw = 0.5 ETB kg^{-1}; Cost of NPS fertilizer = 14.50 ETB kg^{-1}, Labor cost for fertilizer application=3 ETB kg^{-1}

development of the crop. Likewise, Getahun *et al*. [55] who reported that the application of N and P resulted in increased straw yields about 129% compared to the control. Similar results were found by Wakjira [56] indicated that the application of 120kg NPS fertilizer gave the highest straw yield (6.32 t ha^{-1}) while the lowest straw yield (5.53 t ha^{-1}) was recorded from nil NPS fertilizer. Similarly, Teklay and Girmay [9] who reported that, straw yield of teff was significantly affected by application of blended fertilizer which exceeds 7% and 490% over the recommended NP and control plots respectively.

Lodging Index: Lodging index was highly significant (P<0.01) on the main effects of varieties and NPS fertilizer rates. However, the interaction effect of two factors was not significant (Table 5). The highest lodging (45.47%) was recorded from local cultivar which was statistically at par with Nigus variety with mean Lodging index of 45.33%, while the lowest lodging index (34.08%) was recorded from Dagem variety (Table 5). This is because of the genetical variability of the varieties.

The highest lodging (80%) was recorded from the highest fertilizer rate (200 kg NPS ha^{-1}), while the lowest lodging index (11.75%) was recorded from un-fertilized plot (Table 5). The highest lodging might be due to 200 kg NPS ha^{-1} of fertilization that enhanced fast vegetative growth, plant height and succulent stem elongation of teff and the wind prevailed in the study area. Also, Shiferaw [40] reported highest lodging of teff (74%) at N/P_2O_5 rate of 64/46 kg ha^{-1}. Likewise, Fayera *et al.* [44] reported the highest lodging percentage (79.74%) of teff with the highest rate of NPK (138 kg N ha^{-1} combined with 55 kg P ha^{-1} and 0 kg K_2O ha^{-1}) application. Similarly, Wakjira [56] reported that highest lodging index (62.4%) was recorded from application of 150kg NPS ha^{-1}and the lowest lodging index was obtained from nil fertilizer application. In agreement with Seifu [40] the highest lodging (77%) was recorded from the highest blended 150 kg NPSB ha^{-1} and 69 kg N ha^{-1} fertilizer rate.

Pearson Correlation of Yield and Yield Component of Teff Due to Varieties and NPS Fertilizer Rates: Correlation analysis between yield and yield components of teff revealed strong significant and positive correlation of grain yield with all parameters observed except with lodging index. Grain yield of teff was significant and positively correlated with productive tiller (0.72), total tiller (0.68), dry biomass (0.90), straw yield (0.8), thousand seed weight (0.60) and harvest index (0.41) indicating that, grain yield could invariably increase by managing these attributes (Table 6). This result was supported by findings of Solomon [57] on 18 teff genotypes, which reported that grain yield was positively correlated with plant height, panicle length, shoot biomass and kernel seed weight. Similarly, it was reported that teff grain yield was positively correlated with kernel seed weight and shoot biomass with panicle length [58]. Moreover, Bekalu and Arega [59] reported that grain and straw yields of teff were significantly and positively correlated with plant height and panicle length, but negatively with days to heading and maturity. Another study by Teklay and Girmay [9] revealed that on Cambi and Vertisol teff grain yield was positively correlated with all yield and yield components parameters without lodging index.

Economic Feasibility of NPS Fertilizer Rates on Teff Production: The highest net benefit of 76991 ETB ha^{-1} with marginal rate of return (MRR) of 750% was obtained from application of 150 kg NPS ha^{-1} (Table 7). The lowest net benefit 34903 ETB ha^{-1} was obtained from the control treatment. The highest net benefit and the MRR were found to be above the minimum level. Thus, applications of 150 kg NPS ha^{-1} for teff production were economically feasible as compared to the other treatments in the study area. This implies that for every one birr invested in NPS application, farmers can expect to recover the 1 ETB ha^{-1} and obtain an additional 7.50 ETB ha^{-1}.

This result was in line with Firehiwot [60] report which mentioned that estimated net income for mineral fertilizer is attractive as compared to growing wheat without application of fertilizer. Similarly, Yared *et al.* [52] report that the highest net benefit 46996.74 ETB ha^{-1} with MRR of 45110.56% was obtained in response to application of 69/69 kg NP ha^{-1}. However, the lowest net benefit 26874.99 ETB ha^{-1} was obtained from the treatment without application of both N and P fertilizer.

CONCLUSION

The mean number of total tillers, productive tillers, straw yield and lodging index were highly significantly ($P<0.01$) affected by main effect of varieties and NPS rates. Dry biomass and grain yield were affected significantly ($P<0.05$) by effect of varieties and highly significantly ($p<0.01$) by effect of NPS rates, while harvest index and thousand seed weight were affected significant ($P<0.01$) only by the main effect of varieties. The highest number of total tillers (1478 plant m^{-2}) and productive tillers (1393 plant m^{-2}) were recorded from Dagem with 150 kg NPS ha^{-1} application. Highest dry biomass (10280 kg ha^{-1}) and straw yield (8354 kgha^{-1}) were obtained from Kora which was statistically at par with Dagem (10190 and 8081 kg ha^{-1}), respectively. Highest grain yield (2108 kg ha^{-1}) and thousand seed weight (0.3267 g) were recorded from Dagem, whereas highest harvest index (23.85%) and lodging index (45.33%) were obtained from Nigus and local variety, respectively. The highest grain yield (2367 kg ha^{-1}), dry biomass (11577 kg ha^{-1}) and straw yield (9210 kg ha^{-1}) were obtained with application of 150 kg NPS ha^{-1}. The interactions of the two factors were highly significant on number of productive tillers and significant on number of total tillers. The maximum lodging index (80%) was recorded at 200 kg NPS ha^{-1}. Correlation analysis between yield and yield components of teff were strong, significant and positive except with lodging index. The applications of 150 kg NPS ha^{-1} gave the highest net economic benefit of 76991 ETB ha^{-1} with MRR of 750%. Therefore, it can be concluded that application 150 kg NPS ha^{-1} could be tentatively recommended for production of teff in the study area and other areas with similar agro-ecological conditions. However, since the experiment was conducted for one season at one location, it is suggested that the experiment has to be repeated over seasons and locations using this and other improved teff cultivars to make a conclusive recommendation.

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