Original Research Article

Effects of Nitrogen Fertilizer Rate and Inter-row Spacing on Yield and Yield Components of Teff [*Eragrostis teff (Zucc.*) Trotter] in Limo District, Southern Ethiopia

ABSTRACT

Teff [*Eragrostis tef* (Zucc.) Trotter] is the major staple food of Ethiopia. It ranks the first among cereals in the country in area coverage and second in the production volume; however, its productivity is almost stagnant. The~~eff variety~~ Quncho (Dz-Cr-387) teff vaiety was sown during the main cropping season of 2017 at the Limo District, Southern Ethiopia. The objective of this research was to study the effect of four nitrogen fertilizer rates (0, 32.5, 65 and 97.5kg N/ha$^{-1)}$ and three inter-row spacings (15, 20 and 25cm), to evaluate the effects~~ of nitrogen fertilizer rate and inter-row spacing~~ on yield and yield components of teff and to identify the economically appropriate nitrogen rates and inter-row spacing that maximize the yield of teff. A factorial experiment was laid out in RCBD with 12 treatment combinations and three replications. ~~The p~~Phenological and yield related parameters were measured. ~~The obtained data were subjected to statistical analysis using SAS and means differences were compared using Least Significance Difference.~~ The main effects of N rate and inter-row spacing showed significant differences (P≤0.05) for all yield and yield components~~ studied~~. The effects of N rate by inter-row spacing interaction were not significant for some traits ~~studied~~ except for the lodging index, biomass, grain, and straw yield and harvest index. Application of N rate at 97.5 kg ha^{-1}and inter-row spacing with 25 cm significantly (P≤0.01) increased grain yield of teff. Moreover, both N fertilizer rates and wider inter-row spacing increased the magnitudes of the important yield attributes including plant height, panicle length, number of effective tillers per plant, thousand seed weight, ~~B~~biomass yield and straw yield significantly (P≤0.01) and also inter-row spacing increased the magnitudes of ~~the~~ important yield attributes, including significance~~tly~~ (P≤0.05).

From the results of the study it is possible to conclude that increased application of nitrogen fertilizer rate and row spacing improves yield and yield components of teff. Therefore, the application of 97.5 kg N ha^{-1} and inter-row spacing of 25 cm gave maximum profit which can be recommended for the study area.

Comment [U2]: Is it economically viable?

Keywords: Nitrogen, Inter-row spacing; Teff; and Fertilizer rates

INTRODUCTION

Teff [*Eragrostis teff (Zucc.)* Trotter] is the major staple food crop of Ethiopia [1]. It has the largest value in terms of both production and consumption in Ethiopia [2, 3]. It is ~~M~~mostly used to prepare a spongy flatbread called "*enjera*", which is consumed by about 70% of the Ethiopian people [5, 5]. It is typically hand-broadcasted on the field and, in most cases, seeds are left uncovered [6]. When grown as a cereal, farmers highly value its straw as a source of animal feed, especially during the dry season [7]. Teff straw, besides being the most appreciated feed for cattle, ~~it~~ is also used to reinforce mud and plaster the walls of tukuls and local grain storage facilities called gottera [8, 9, 10]. Moreover, it has got many prospects outside of Ethiopia due to its gluten freeness, tolerance to biotic and abiotic stress, animal feed and erosion control quality [6, 10].

Comment [U3]: Same as in Abstract!

Teff ~~in Ethiopia~~ accounts first in area coverage and second in total annual production next to maize, and ranks the lowest yield compared with other cereals grown in Ethiopia [11, 9]. ~~In Ethiopia, i~~It is cultivated in an area of about 2.8 million hectares which takes~~wing~~ up about 28.5 % of the total grain cropping area [5].

In spite of the aforementioned importance, its productivity is very low (1.46 t ha^{-1}) as compared to other major cereals [11]. Some of the factors contributing to low yield ~~of teff~~ are low soil fertility, suboptimal use of mineral fertilizers, weeds, uneven rainfall distribution in lower altitudes, lack of high yielding cultivars, lodging, water-logging, and low moisture [12]. Farmers in Ethiopian highlands apply N fertilizer in the form of Urea at sub-optimal blanket rates, mostly only once at ~~the time of~~ sowing, and this limits the potential productivity of cereal crops [13]. Farmers in the Limo district also apply low amounts of nitrogen only one time at sowing ~~for teff~~

production. In general, blanket recommendations, regardless of considering the physical and chemical properties of the soil as well as the application of full dose at one time, do not lead to increase the teff productivity.

Even if producers do not give attention to teff row spacing, it has an advantage for shorter maturity days, higherrst plant height and panicle length, a greater number of tillers and less lodging percentages which helps to improve grain yield of teff [14]. Those above-aforementioned problems are real challenges in the study area. There is significant reduction of yield of teff in the Limo district due to usage of inappropriate row spacing and lack of area-specific N rate application. Therefore, it is of paramount importance and initiated to develop and recommend appropriate row spacing and optimum rate of N fertilizer for maximizing teff production in the study area.

MATERIALS AND METHODS

The experiment was conducted at Wachemo University experimental site in Limo district, Southern Ethiopia (include geographical coordinates) in the 2017 cropping season. The area receives a mean annual rainfall of 1800 mm with mean maximum temperature of 16 24 ^{0}cC and a minimum of 16 ^{0}cC (Fig 1)). Soil physical and chemical properties of the study area (Table 1).

Parameters	Value	Rating	Reference	Remark
Total nitrogen (%)	0.11	Low	Havlin *et al*. [15]	Deficient
Available phosphors (mgkg^{-1})	9.4	Medium	Olsen *et al.* [16]	Sufficient
Organic carbon (%)	1.24	low	Roy *et al*. [17]	Deficient
Organic matter Content	2.13	Low	Sahlemedhin [18]	Deficient
pH (H_20)	6.4	Slightly Acidic	FAO [19]	Suitable
Cation Exchangeable Capacity (meqkg^{-1})	20.4	Medium	Sahlemedhin [20]	Sufficient
Sand (%)	26%	Clay (%)	24%	
Silt (%)	50%	Texture class	Silty loam	

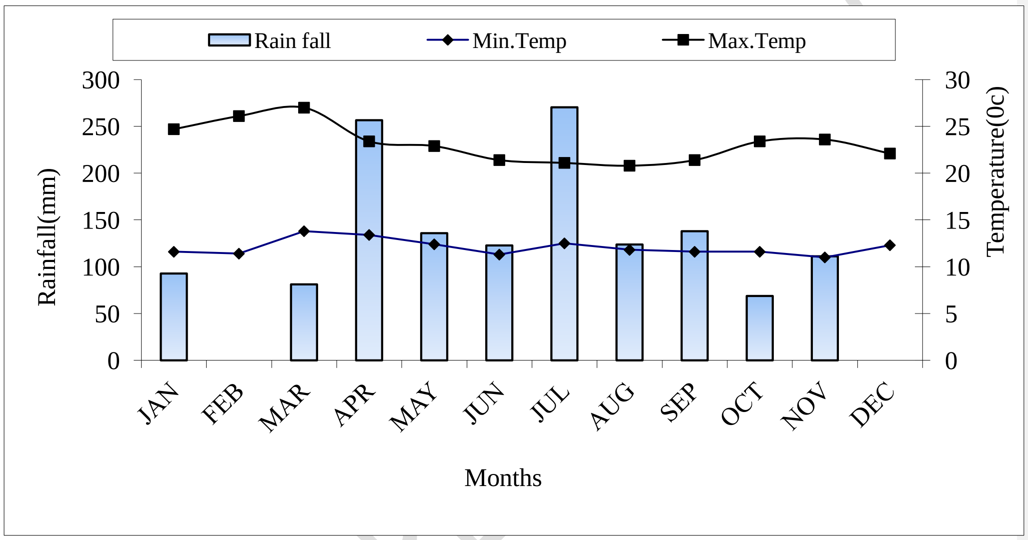

Figure 1. The minimum and maximum Temperature and Mean Rainfall of the experimental area during 2017-years (Source: Hawassa Meteorological Data Station (2017))

Treatments and Experimental Materials

The experiment was designed in factorial randomized complete block design consisting of four levels of N fertilizer rates (0, 32.5, 65 and 97.5 kg/ha) and three rows spacings (15, 20 and 25 cm).

Each treatment was replicated three times, with and there were twelve treatment combinations. Each plot had an area of 1.5 m * 2.25 m. The row spacings of 15, 20 and 25 cm had 15, 11 and 9 rows, respectively. The net plot size was 2.34 m^2 and a spacing of 0.5 and 1 m was maintained respectively between plots and replications. The Quncho (Dz-CR-387) teff variety, which is released by Debre Zeit Agricultural Research Center, was used for the experiment.

Field Management practices

Land preparation was done according to farmers' practice in the area and leveling was carried out manually to ensure better seedbed for the small seeds of teff. All TSP and half of the Urea were applied at the time of sowing for row planting. The remaining Urea was applied at the tillering stage of the crop. This was doneue to reduce leaching losses of nutrients and to harmonize the supply with the crop demand. Moreover, weeding was done alike to farmers' practice in the area.

Comment [U4]: What is that? Spell it out!

Soil Sampling and Analysis

A composite soil sample from the depth of 0-15 cm layer was taken independently, at from 10 representative spots. The soil physio-chemical parameters were analyzed for this study. Soil organic matter was determined by following Walkley and Black method [21]. Soil pH was determined in 1:2.5 soil: water ratio using a glass electrode attached to a digital pH meter. Total N was determined by the Kjeldahl method [22]. Available P was determined by Olsen and Bray II method [23]. Soil Cation exchange capacity was determined by using 1 M ammonium acetate.

Data Collection and Measurements

Phenological Parameters

Days to panicle emergence was recorded as the number of days from seedling emergence to the time when the tips of panicles of at least ten first emerged from the main shoot in each plot. Days to physiological maturity was taken as the number of days elapsed from seedling emergence to the date when 90 % of the crop stems, leaves and floral parts in a plot changed to a light yellow color. Plant height was measured as the height of plants in centimeters from the base of the main stem to the tip of the panicle and recorded as the average of ten randomly selected plants. Panicle length was measured as the length of the panicle ~~in a centimeter~~ of the main shoot from the node where the first panicle branch starts to the tip of the panicle, as the average of ten randomly selected plants at physiological maturity.

Yield Parameters

The number of fertile tillers was counted including the main shoot from an area of ten randomly selected plants from each plot. 1000-seed weight was determined ~~by taking 1000 seed from each plot~~ using a sensitive balance. Grain yield was recorded as the weight of the air-dried seeds harvested from the net plot size of each plot in kg. For analysis, g/plot was converted to kg/ha. The straw yield was determined by subtracting grain yield from above-ground dry biomass yield. Biomass yield at maturity, the whole plant parts, including leaves and stems, and seeds from the net plot area were harvested, and after drying, the biomass was measured. Harvest index was recorded as the ratio of grain yield to shoot biomass at harvest in kg from the net plot.

Lodging Percentage

The degree of lodging was assessed just before the time of harvesting by visual observation based on the scales of 1-5. Where 1 (0-15%) indicates no lodging and 5 (60-90%) indicates 100% lodging [24]. The scales were determined by the angle of inclination of the main stem from the vertical line to the base of the stem by visual observation.

Statistical Data Analysis

The Data were subjected to analysis of variance (ANOVA) procedures by using SAS version 9.3 with a general linear model procedure. Mean separation (mean differences comparison) was undertaken by the Least Significant Difference test at 5 percent level of significance.

RESULTS AND DISCUSSIONS

Days to 50 % Panicle Emergence

The analysis of variance indicated that days to panicle emergence ~~of teff~~ were significantly ($P<0.01$) affected by the main effects, but their interaction was not significantly ($P>0.05$) different (Table 1).

Application of N at 97.5 kg ha^{-1} significantly delaiedy~~y~~ panicle emergence in relation to ~~than that of~~ the other treatments (Table 1). The prolonged number~~in~~ of days to panicle emergence was due to N application might be high N levels promoted excessive vegetative growth and development of the plants possibly due to synchrony of the time of need of the plant for the uptake of the nutrient and availability of the nutrient in the soil. This result is incoherent with the findings of Haftamu [25] who reported that a significantly prolonged number of days to heading in response to N application.

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Comment [U6]: Also with problems

Similarly, panicle emergence was also significantly delayed with the successive enlargement in-row spacing (Table 1). The earlier ~~in~~ panicle emergence due to slender row spacing might have~~be~~ reduced the rate of photosynthesis because of the competition of plants for light, space, nutrients, and water. In conformity with the present study, Gorgy [26] reported one day earlier panicle emergence in plots with 15 cm in relation to~~than with~~ 25 cm row spacing.

Days to physiological Maturity

The analysis of variance showed that days to 90% maturity were significantly ($P<0.01$) affected by the main effects but their interaction effects were not significantly ($P>0.05$) different (Table 1).

Application of a high rate N delayed teff maturity, ~~in teff~~ which was significant with the increase in nitrogen application rates (Table 1). Hence, it was postponed by twenty-seven days in response to receiving 97.5 kg N ha^{-1} , in relationto~~than that of~~ the control treatment (Table 1). This might be attributed to an increase of~~the formation of~~ chlorophyll, which keeps the plant photosynthetically active for a longer period. This result, is incoherent with the findings of Temesgen [27] who found that high N application rates caused physiological maturity to delay due to the direct effect of N on the vegetative growth in teff.

Physiological maturity was significantly earlier at the closer inter-row spacing of 15 cm, in relation to ~~than~~ 20 and 25 cm row spacings (Table 2). The earlier ~~in~~ physiological maturity due to closer row spacing might be the presence of intense inter-space competition which led to the depletion of the available nutrients and as result plants tended to mature earlier. The current finding was in accordance~~proportion~~ to the work of Wubante [28] who concluded that plants grown at 15 cm row spacing significantly shortened days to 90 % physiological maturity than those grown at the wider row spacings.

Plant Height

Plant height were significantly (P<0.01) affected by the main effects but their interaction was not significantly (P>0.05) different (Table 1).

The plants attained significantly maximum plant height with a further increase in the N application rate. Thus, the highest plant height (125.02 cm) was obtained with the application of 97.5 kg N ha^{-1} which was 39.5 %, 26.23 % and 8 % greater than the control, 32.5, 65 kg N ha^{-1}, respectively (Table 1). This may be caused by the fact~~characterized~~ that N usually favors vegetative growth of teff, happening in the higher status of the plants with the tallest plant height. In line with this result, Haftamu [25] described that teff with greatest~~upper~~ plant height was obtained by applying a maximum amount of nitrogen rate.

The inter-row spacing of 25 cm resulted in significantly higher plant height (103.82cm) than 15 cm row spacing. The plants in 25 cm row spacing were 4 % and 1.18 % taller than the plants in 15 and 20 cm row spacing, respectively (Table 1). This might be due to less competition of crops for nutrients that provide a better environment for the growth and development of the crop. Similarly, Mahato [29] reported that maximum plant height was obtained with wider spacing as compared to closer spacing in rice.

Table 1. Days to 50% panicle emergence, days to 90% physiological maturity and plant height were influenced by nitrogen fertilizer rates and inter-row spacing on teff in Limo district, SNNPR in 2017 main cropping season

Main Effect	PE	PM	PH
N- rate (Kg/ha)			
0	55.3^{d}	99.4^{d}	75.82^{d}
32.5	60.5^{c}	107.3^{c}	92.23^{c}
65	67.2^{b}	117.5^{b}	114.96^{b}
97.5	71.4^{a}	126.4^{a}	125.02^{a}
LCD	2.134	3.916	3.842
Row Spacing (cm)			
15	61.25^{b}	108.16^{b}	99.6^{b}
20	64.58^{a}	114.58^{a}	102.59^{ba}

25	64.92^a	115.08^a	103.82^a
LCD	1.848	3.391	3.328
CV (%)	3.43	3.56	3.85

LCR: Means of Least Critical range; CV: Coefficient of Variance, PE: Panicle Emergence, PM: Physiological Maturity, PH: Plant Height, Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different at 5% probability level.

Panicle Length

The analysis of variance indicated that the main effect of nitrogen fertilizer rates was highly significantly (P≤0.01) affected panicle length and also row spacing was significantly (P≤0.05) influenced panicle length. However, the interaction factors were not significantly (P≥0.05) different (Table 2).

Panicle length is one of the yield attributes that contribute to grain yield. An increase in the rate of N application increased the panicle length of teff. Thus, the maximum panicle length (44.9) was recorded when 97.5 kg ha^{-1} N wereas applied, which was 23.4 %, 16.35 %, and 8.9 % higher than the control treatment, 32.5 and 65 kg N ha^{-1}, respectively (Table 2). Having a long panicle is directly related to the yield of teff. The increment in panicle length due to higher N application might be the better N position of plant during the panicle growth period. Consistent with this result, Awan [30] reported the highest panicle length found in treatments receiving higher nitrogen rates.

The outcome of this study showed that wider inter-row spacings (25 and 20 cm) led to significantly higher panicle lengths than the closer spacing of 15 cm inter-row spacing (Table 2). The improvement in panicle length due to wider row spacing was probably due to the greater more availability of growth resources and might be an increase in chlorophyll formation. Consistent with this study, Hasanuzzaman [31] reported the higher number of tillers obtained in the widely spaced plants was more effective in mobilizing photosynthates for panicle length and grain filling, compared to closely spaced plants resulting in a higher number of panicle length.

Number of Fertile Tillers

The number of fertile tillers wasere significantly ($P<0.01$) affected by the main effects but their interaction was not significantly ($P>0.05$) different (Table 2).

In the current study, it was found that with the successive increase in nitrogen application rates, the number of effective tillers also increased significantly. The maximum numbers of effective tillers (13.79) were obtained with the application of 97.5 kg N ha^{-1} ,which was higher by 56.3, 38.22 and 11.53 %, over the control treatment, 32.5, and 65 kg N ha^{-1}, respectively (Table 2). This might have been obtained due to the greatermore availability of N that might have played a vital role in cell division. Consistent with these results, Haftamu [25] reported a significantly greater maximum number of tillers in response to the application of a high N rate in tef.

Increasing row spacing from 15 cm to 25 cm increased the number of effective tillers. However, the number was significantly greater with 20 and 25 cm row spacing than with 15 cm row spacing. However, no significant differences were observed between 20 and 25 cm of inter-row spacing. The increase in the number of effective tillers with 20 and 25 cm was 18.9 % and 21.5 %, respectively over 15 cm row spacing (Table 2). This may probably be due to a better access to space, nutrients, water, and light in wider spacing. Similarly, Sultana [32] found the highest number of effective tillers with 25 cm row spacing in rice.

Thousand Seed weight

The analysis of variance indicated that the thousand seed weight wasere significantly ($P<0.01$) affected by the main effects, but their interaction was not significantly ($P>0.05$) different (Table 2).

This study indicated that the application of nitrogen rate influenced thousand seed weight. The highest thousand seed weight (0.388 gm) was recorded at an N rate of 65 kg/ha and the lowest (0.284 gm) was recorded from the control treatment (Table 3). However, these nitrogen rates had significantly higher thousand seed weight than that of the control treatment. The improvement in 1000 Seed weight due to N application rate might be the increase in chlorophyll concentration which led to a higher photosynthetic rate for grain development and then, reducinge with further application of N~~ rate~~ (Table 2). In line with this result is~~,~~ Ahmed [33] ,who found that the weight of 1000-grains was maximum when nitrogen applied at a rate of 40 kg ha^{-1} in rice.

The results showed that with the increase in inter-row spacing the thousand seed weight also increased slightly. Thousand seed weight was slightly maximums at 25 cm inter-row spacing as compared to 20 cm but statistically not significant~~ difference~~ between them. However, the lowest 1000-seed weight was recorded at 15 cm inter-row spacing (Table 3). Higher 1000-seed weight noted in wider rows might be a more efficient utilization of water, nutrients, and light due to minimal inter-rows competition and lower plant population~~ in teff~~. The results are in line with thoseat of Alaunyte [34] who obtained increased grain weight at wider row spacing (22.5 cm) for ~~in~~ teff.

Table 2. Panicle length (cm), effective tillers (No) and thousand seed weight (gm) were influenced by nitrogen fertilizer rates and inter-row spacing on teff in Limo district, SNNPR in 2017 main cropping season

Main Effect	PL	ET	TSW
N-Rates (Kg/ha)			
0	34.39[d]	6.02[d]	0.284[d]
32.5	37.56[c]	8.52[c]	0.334[b]
65	40.9[b]	12.2[b]	0.388[a]
97.5	44.9[a]	13.79[a]	0.358[b]
LCR	2.474	1.293	0.02611
Row Spacing (cm)			
15	37.63[b]	8.65[b]	0.306[b]
20	39.96[a]	10.67[a]	0.357[a]
25	40.74[a]	11.02[a]	0.368[a]

LCR	2.142	1.120	0.02261
CV (%)	6.42	13.08	8.28

LCR: Means of Least Critical range; CV: Coefficient of Variance, PL: Panicle Length, ET: Effective Tillers, TSW: Thousand Seed Weight, Means followed by the same superscript letters are not significantly different at 5% probability level.

Biomass Yield

The analysis of variance showed that biomass yield was~~ere~~ significantly (P<0.01) influenced by both the main as well as by interaction effects (Table 3). Biomass yield generally increased highly significantly (P≤0.01) with the increase in the rate of nitrogen across the increasing inter-row spacing. The highest biomass yield (1313.3 Kg/ha) was found from a combination of 97.5 kg N ha^{-1} with 25 cm row spacing. Whereas, the lowest biomass yield (8046.7 kg/ha) was obtained from a combination of control with 15 cm inter-row spacing (Table 3). Hence, ~~further,~~ an increase in N rates and wider row spacingof the aboveground dry biomass~~, yield~~ increased yield significantly.

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The main effect of N fertilizer rates was highly significantly (P≤0.01) affected by the biomass yield of teff. The highest biomass yield (12607.78) was achieved from a 97.5 kg N ha^{-1} application. Whereas, the lowest biomass (8374.44) was obtained from control treatment (Table 3). In general, the further increase in nitrogen fertilizer rate increased the biomass yield of teff. Similar results were reported by Dutta [35] who found the highest biomass yield by applying high N ha^{-1}. The increment in biomass yield due to high nitrogen might be high N application positively causes high vegetative growth and enlargement of stem cells that consequently increased biomass yield.

Comment [U7]: Above in yellow you say 1313.3!!! very different from 12607.78!

Comment [U8]: ??? difficult

Row spacing was ~~highly~~ significantly (P≤0.01) affected the biomass yield~~ of teff~~. The highest biomass yield (10970.8) was observed from plants that were planted ~~at~~with 25 cm inter-row spacing and the lowest biomass yield (10227.5) was obtained from 15 cm inter-row spacing followed by 20 cm (Table 3). In general, a further increase in inter-row spacing increased biomass yield. The increase in aboveground dry biomass in response to increasing (widening) the inter-row spacing might be due the better environment for growth and development of the crop that might have~~be~~ resulted in improved plant height, more effective tillers and panicle length

(Table 1and 2). Ali [36] also found increased biomass yield with wider inter-row spacing due to higher production of tillers in rice.

Grain Yield

Grain yield was~~ere~~ significantly (P<0.01) affected by both,~~ by~~ the main as well as by interaction effects (Table 3). The interaction effects of nitrogen fertilizer rates and row spacing were ~~highly~~ significantly (P≤0.01) affected grain yield~~ of teff~~. The highest grain yield (3403.3 kg/ha) was observed for the~~from a~~ combination of 97.5 kg N ha^{-1} with 25 cm inter-row spacing. While the minimum grain yield (1690 kg/ha) was observed for~~rom~~ the control treatment with 15 cm inter-row spacing (Table 3). In general, a further increase in N rate and row spacing increased the grain yield of teff. An increase in grain yield due to the application of nitrogen rate and wider row spacing might have been due to the improvement of yield contributing characters, like the number of effective tillers and panicle length (Table 2). Therefore, the higher the number of tillers, especially fertile tillers, the higher~~more~~ will be the yield.

Grain yield was ~~highly ~~significantly (P≤0.01) affected by the main effects of nitrogen fertilizer rates. The highest grain yield (3148.89) was obtained from plants that were supplied with 97.5 kg N ha^{-1} and the lowest grain yield (2065.56) was obtained from the control. However, there was no significant difference between 32.5 and 65 kg N ha^{-1} (Table 3). In general, a further increase in nitrogen fertilizer rates increased grain yield~~ of teff~~. Increased grain yield due to increased N application was also reported for different cereal crops. Nitrogen supply directly or indirectly affects chlorophyll content, LAI, canopy coverage and other biophysical parameters [37].

Likewise, the main effect of row spacing was ~~highly ~~significantly (P≤0.01) affected grain yield ~~of teff~~. The highest grain yield (2886.67and 2839.17) was obtained from plants that planted at 20 and 25 cm row spacing, respectively. However, the lowest (2453.3) was obtained from 15 cm row spacing (Table 3). The results of this study were in line with those~~at~~ of Sultana [32] who reported that yields of cereals increased as the spacing between rows increased because plant populations are normally high in narrow spacing (15 cm).

Table 3. Grain yield (Kg/ha) were affected by interaction as well as by the main effects of nitrogen rates and inter-row spacing in Limo District, SNNPR in 2017 main cropping season

	BY				GY			
N- Rate	Row Spacing (cm)				Row Spacing (cm)			
(Kg/ha)	15	20	25	Mean	15	20	25	Mean
0	8046.7^{i}	8423.3^{h}	8653.3^{h}	8374.44^{d}	1690.00^{h}	2173.3^{g}	2360.0^{f}	2065.56^{d}
32.5	9500.0^{g}	10160.0^{f}	10476.7^{e}	10045.56^{c}	2436.67^{f}	2816.7^{e}	2860.0^{ed}	2788.89^{b}
65	11336.7^{d}	11313.3^{d}	11580.0^{d}	11410.00^{b}	2883.3^{ed}	3103.3^{cb}	3176.7^{b}	3148.89^{a}
97.5	12026.7^{c}	12623.3^{b}	13173.3^{a}	12607.78^{a}	3000.0^{cd}	3166.7^{b}	3403.3^{a}	2902.22^{b}
Mean	10227.5^{c}	10630^{b}	10970.8^{a}		2453.3^{b}	2886.67^{a}	2839.17^{a}	
LCR	306.1				156.2			
CV (%)	1.7				3.35			

LCR: Means of Least Critical range; CV: Coefficient of Variance, BY: Biomass Yield, GY: Grain Yield, Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different at 5% probability level.

Straw Yield

The analysis of variance indicated that the straw yield was affected significantly (P<0.01) by both, ~~by~~ the main as well as by interaction effects (Table 4). The interaction effects of nitrogen fertilizer rates and row spacing were significantly (P≤0.01) affected the straw yield ~~of teff~~. The highest straw yield (9770 kg/ha) was obtained from crops that were applied at rate of 97.5 kg N ha^{-1} with 25 cm inter-row spacing and this is statistically equal to the treatment of~~parity at~~ 97.5 kg N ha^{-1} with ~~the~~ 20 cm row spacing (9456.7 kg/ha). While the lowest straw yield (6250 kg/ha) was obtained for~~rom~~ the control with 20 cm inter-row spacing (Table 4). From this study, the straw yield increased significantly with an increase in the rate of nitrogen application and inter-row spacing. The higher straw yield at higher N rates and wider inter-row spacing that could probably be the outcome of more leaf area, higher interception of solar energy and high absorption of nutrients which might have brought about higher photosynthetic efficiency for dry matter production.

The straw yield was highly significantly (P≤0.01) affected by the main effects of the nitrogen fertilizer rate. The highest straw yield (9705.56) was attained from plants that were supplied with 97.5 kg N ha^{-1} and the lowest was obtained from the control treatment (Table 4). Similar to the results of this study, Rahman [38] reported that nitrogen influenced vegetative growth in terms of plant height and number of tillers (Table 1 and 2) which resulted in increased straw yield (Table 4). The increase in straw yield in response to the application of N fertilizer might be due to the greater availability and uptake of the nutrients by plants, and the resulting induction of vigorous vegetative growth with more leaf area, and the resulting in higher photosynthesis and assimilates production andfor dry matter accumulation [39].

The main effect of row spacing was highly significantly (P≤0.01) affected straw yield. The highest straw yield (8131.67) was obtained from plotsants that planted at 25 cm row spacing and the lowest straw yield (7774.17 and 7743.3) was obtained forrom plants that sown at 15 and 20 cm row spacings, respectively. However, there wasis no significant difference between 15 and 20 cm row spacings (Table 4). In general, a further increase in row spacing increased the straw yield of teff. The highest straw yield obtained from wider row spacing might be t5hewider spacing due to higher production of plant height and number of effective tillers. This result agrees with Yoseftabar [40], who reported that the straw yield was significantly influenced by the successive increase in-row spacing.

Harvest Index

The Hharvest index wasere significantly (P<0.01) affected by both, main as well as by interaction effects (Table 4). The interaction effect of N fertilizer rates and row spacing were also highly significantly (P≤0.01) affected the harvest index. Thus, the maximum harvest index (27.7%) was obtained from plants that were supplied a nitrogen fertilizer rate of 32.2 kg N ha^{-1} with 20 cm spacing. whereas, the lowest harvest index (21.00%) was observed forrom the control with 15 cm inter-row spacing (Table 4). The dData suggested that nitrogen levels from 65 to 97.5 kg/ha^{-1} decreased the harvest index (Table 4). The maximum harvest index was obtained forrom the more or lowess increase in N application and then decreased with extra increase in N rates, this might be due to minor biomass partitioning to grain production. This finding was in agreementcovenant with thatose of Hasanuzzaman [31, 40] who obtained higher harvest indexes in rice with low~~more or less~~ increased N rates and decreased with further increase in N application.

The harvest index was ~~highly~~ significantly (P≤0.01) affected by the main effects of the nitrogen fertilizer rate. The highest harvest index (27.68 and 27.61) was obtained from plants that supplied 32.5 and 65 kg N ha^{-1}, respectively. The lowest harvest index was obtained from plants that supplied nitrogen at 97.5 kg ha^{-1} (Table 4). In general, a further increase in the N rate decreased harvest index. This finding was in agreement with those of Mahato [29] who obtained higher harvest index in rice with the more or less increased nitrogen application rates and decreased finally with further increase in the application of nitrogen fertilizer.

Likewise, row spacing was also highly significantly (P≤0.01) affected the harvest index. The maximum harvest index (27.27 and 26.185) was obtained from plants that planted at 20 and 25 cm row spacing, respectively. The minimum harvest index (23.77) was obtained from 15 cm row spacing (Table 4). In general, a further increase in row spacing increased harvest index. The increment in harvest index due to wider row spacing might be less intra-specific competition led to a greater proportional increase in grain yield than biomass accumulation. Similarly, Hussain [41] found that higher harvest index was reported in 20 cm row spacing, but statistically similar with 25 cm row spacing in wheat crop.

Table 4. Straw yield (Kg/ha) and Harvest Index (%) were affected by interaction as well as by the main effects of nitrogen rates and inter-row spacing in Limo District, SNNPR in 2017 main cropping season

	SY				HI			
N- Rate (Kg/ha)	Row Spacing (cm)				Row Spacing (cm)			
	15	20	25	Mean	15	20	25	Mean
0	6356.7^{f}	6250.0^{f}	6293.3^{f}	6308.89^{d}	21.00^{d}	25.8^{bc}	27.4^{ba}	24.5956^{b}
32.5	7063.3^{e}	7343.3^{ed}	7616.7^{d}	7256.67^{c}	25.67^{bc}	27.7^{a}	27.3^{ba}	27.6800^{a}
65	8453.3^{c}	8210.0^{c}	8403.3^{c}	8261.11^{b}	25.4^{c}	27.4^{ba}	27.42^{ba}	27.6100^{a}
97.5	9026.7^{b}	9456.7^{a}	9770.0^{a}	9705.56^{a}	24.9^{c}	25.08^{c}	25.85^{bc}	23.0789^{c}
Mean	7774.17^{b}	7743.3^{b}	8131.67^{a}		23.77^{b}	27.27^{a}	26.185^{a}	
LCR		317.3				1.634		

CV (%)	2.39	3.72

LCR: Means of Least Critical range; CV: Coefficient of Variance; SY: Straw Yield, HI: Harvest Index, Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different at 5% probability level.

Lodging Index

The analysis variance indicated that the main, as well as interaction effects, were significantly (P<0.01) influenced the lodging index (Table 5). The interaction effects of nitrogen fertilizer rates and row spacing were highly significantly influenced by the lodging index. The highest lodging index was observed from crops ~~that nitrogen applied~~ at the rate of 97.5 kg ha^{-1} with 15 cm (57.17%) inter-row spacing. Whereas, the lowest was obtained from the control with 20 cm (41.13%) row spacing, ~~and this is statistically parity~~ with no difference to the control with 25 cm (41.43%) inter-row spacing (Table 5).

The main effect of N fertilizer rates was highly significantly (P≤0.01) influenced the lodging index. The highest lodging index (54.9) was obtained from plants supplied with 97.5 $kgNha^{-1}$ and the lowest (41.9) was obtained from the control (Table 5). In general, a further increase in N application rates increased the lodging index of teff. This could be due to the profound effect of high N supply on increasing vegetative growth, thereby leading to bending of a~~the~~ weak stem of the plant due to the sheer load of the canopy. Similarly, Temesgen [27] obtained significant differences in the lodging percentage of teff due to N application.

Likewise, the main effect of row spacing was significantly affected lodging index. The highest lodging index (49.45) was recorded from plants that planted at 15 cm row spacing and the lowest lodging index (48.63) was noted from plants that planted at 25 cm inter-row spacing followed by 20 cm (Table 5). The highest lodging index due to narrow spacing might be the result~~ing in~~ of dense crop population and slight stem. The present result is in agreement with Alaunyte [14] who reported that row spacing for teff showed highly significant differences in lodging for~~when there is~~ narrow ~~in~~ row spacing, when there was an increase in lodging percentage.

Table 5. Lodging index (%) were affected by interaction as well as by the main effects of nitrogen rates and inter-row spacing in Limo District, SNNPR in 2017 main cropping season

	LI			
N- Rate (Kg/ha)	Row Spacing (cm)			Means of overall N-Rate
	15	20	25	
0	43.2[g]	41.13[h]	41.4[h]	41.9[d]
32.5	49.00[e]	45.8[f]	45.2[f]	46.65[c]
65	48.5[e]	50.4[d]	54.6[b]	51.16[b]
97.5	57.4[a]	54.2[cb]	53.3[c]	54.9[a]
Means of overall Spacing	49.45[a]	47.88[c]	48.63[b]	
LCD		1.167		
CV (%)		1.42		

LCR: Means of Least Critical range; CV: Coefficient of Variance; LI: Lodging Index, Means within the same column and within the same treatment category followed by the same superscript letters are not significantly different at 5% probability level.

~~SUMMARY AND~~ CONCLUSION

~~Teff is one of the most significant staple foods of Ethiopia, but production is not satisfactory due to various factors like lack of blanket recommendation of N rates and row spacing in the region. A field experiment was carried out during the cropping season of 2017 at the Wachemo University experimental site in Southern Ethiopia with the objective of determining the effects of N fertilizer rate and inter row spacing on yield and yield components of teff. The combinations of four levels of N (0, 32.5, 65 and 97.5 kg N/ha) and three rows spacing (15, 20 and 25 cm) were used as treatments.~~

Application of nitrogen and row spacing significantly influenced most of the plant phenology, growth parameters, yield and yield components of teff. Thus, the highest dose, *i.e.* 97.5 kg N/ha and wider spacing (25 cm) proved to be superior to the dose of the other with respect to enhancing most of these attributes/characters of the teff. Generally, the study revealed that the teff crop responded more to N fertilization and wider row spacing. This shows that 97.5 kg N/ha and 25 cm row spacing should be employed to increase the productivity of the crop rather than using 65 N kg/ha and 20 cm row spacing currently used in the study area. Therefore, taking the finding of the present study into consideration, it may be tentatively concluded that farmers in the Southern region may apply a combination of 97.5 kg N ha^{-1} with 25 cm row spacing to improve the grain yield of teff. Due attention needs to be given to the following issue and direction in the future research program: the present experiment has to be conducted for four seasons across locations of similar agroecology and soil type condition, for the recommendation of the appropriate N ratedose and row spacing on teff.

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