SOIL & CROP SCIENCES | RESEARCH ARTICLE

Tef [Eragrostis tef (Zucc)] grain yield response to nitrogen fertilizer rates in East Badewacho district, Hadiya Zone, Southern Ethiopia

Tamirat Wato

Abstract: Soil fertility depletion is the most important concern all over the world mainly in Sub-Saharan African. The principal one is N fertilizer and it is the most yield-limiting nutrients for crop growth, development as well as production. However, most farmers applied a limited N fertilizer rate for tef production. Hence, a study was to investigate the effects of four nitrogen fertilizer rates (0, 30, 60, and 90 kg N/ha⁻¹), on the grain yield of tef. The study was carried out in a randomized complete block design with three replications in East Badewacho district at the farmers training center in the 2019 cropping season. All the relevant data were collected and then subjected to SAS software 9.4 and mean differences were compared using LSD at 5%. The effects of the N rate showed significant differences (P ≤ 0.05) for all parameters of tef studied. Application of N rate at 90 kg ha⁻¹ was significantly (P ≤ 0.01) improved yield and yield components of tef. Furthermore, N rates increased the magnitudes of all the important yield attributes. Hence, it is tentatively thinkable to conclude that a further supply of N fertilizer rate advances yields components of crops. Thus,

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PUBLIC INTEREST STATEMENT

Soil fertility is one of the common constraints in the world mainly in Sub-Saharan Africa particularly in Ethiopia to maintain food security and poverty alleviation in Ethiopia. Most of the farmers in the highlands of Ethiopia particularly at East Badewacho district, regardless of using optimum blanket N fertilizer rates to boost the production and productivity of the crop, apply only 60 kg N ha⁻¹ and other TSP fertilizers to tef which is not sufficient to meet the crop nutrient demand for the ideal growth, development, and productivity. Due to the above-mentioned reasons, the average yield of tef is still now stagnant as compared to tef crop productivity elsewhere. This stagnant yield is mostly associated with the reduction of soil fertility owing to incessant nutrient uptake of crops and below optimum fertilizer use. In order to minimize such problems, there is a need to scheming site-specific optimum fertilizer recommendations. Therefore, an appropriate supply of N fertilizers has increased tef production.
the application of 90 kg N ha$^{-1}$ gave the highest yield which can be suggested for the East Badewacho areas.

**Subjects:** Agriculture & Environmental Sciences; Botany; Plant & Animal Ecology; Soil Sciences

**Keywords:** tef; nitrogen rate; tef grain yield

1. **Introduction**

In Ethiopia, tef is the major staple food crop and it has the largest value in terms of both production and consumption (Lee, 2018; Nandeshwar et al., 2020). It is mostly used to prepare a spongy flatbread called “enjera” (Wato, 2019), which is consumed by about 70% of the Ethiopian people (Firdisa, 2016; Tamirat & Tilahun, 2020). It is typically hand-broadcasted on the field and, in most cases, seeds are left uncovered (Sate & Tafese, 2016). When grown as a cereal, farmers highly value its straw as a source of animal feed, especially during the dry season (Cheng et al., 2017; Lakew & Berhanu, 2019; Tesfahun, 2018). In addition to this straw is being the most valued feed for livestock (Redden, 2012), it is also used to reinforce mud and plaster the walls of tukuls 1 and local grain storage (Lakew & Berhanu, 2019), facilities called “gottera” (Amare & Adane, 2015). 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 (Amare & Adane, 2015; Sate & Tafese, 2016; Tamirat & Tilahun, 2020).

In Ethiopia, tef 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 (Lakew & Berhanu, 2019; Tesfahun, 2018). Tef is cultivated in an area of about 2.8 million hectares which taking up about 28.5% of the total grain crop area (FAO (Food and Agriculture Organization of the United Nations), 2015; Firdisa, 2016; Nascimento et al., 2018; Wato, 2019).

Despite the abovementioned importance, its productivity is very low (1.48 t ha$^{-1}$) as compared to other major cereals (CSA (Central Statistical Authority), 2016). According to Fenta (2018) reported that some of the factors contributing to low yield of tef 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 (Wakjira, 2018; Tamirat & Tilahun, 2020). According to Sakatu and Legesse (2018) reported that 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 (Tamirat & Tilahun, 2020). Too, farmers in the study area apply low amounts of Urea fertilizer at a sub-optimal blanket rate of 60 Kg/ha only one time at sowing for tef production. Similarly, Bekele et al. (2000) and Kassaye et al. (2020) reported that farmers in Ethiopian lowland area apply N fertilizer in the form of Aberaurea at a sub-optimal blanket rate of 46 kg ha$^{-1}$of N in the form of urea mostly only once or twice at the time of sowing, and this limits the potential productivity of cereal crops. Therefore, optimal approvals irrespective of taking the soil physicochemical characterization as well as the application of full dose at one time during sowing/planting, do not lead to an increase in the tef production and productivity.

Those above-mentioned problems are a real challenge in the study area. There is a significant reduction of yield of tef in the East Badewacho district due to a lack of area-specific N rate application. Thus, it is very important as well as an initiative to develop the optimum blanket N fertilizer rates for enhancing tef production and productivity in the study area.

2. **Materials and methods**

2.1. **Description of the study area**

East Badewacho district is one of the 10 districts in the Hadiya Zone, Southern Ethiopia. The experiment was conducted in the East Badewacho district at the farmers training center in the
2019 main cropping season. The area receives a mean annual rainfall of 1800 mm with a mean maximum temperature of 16–24°C and a minimum of 16°C (Figure 1). Soil physical and chemical properties of the study area (Table 1). Cereal crops are mainly grown and produced in the area like barley, tef, wheat, maize, and sorghum.

2.2. Treatments and experimental materials
The experiment was designed in a randomized complete block design consisting of four levels of N fertilizer rates (0, 30, 60, and 90 kg/ha). Each treatment was replicated three times. Each plot had an area of 1.5 m × 2.25 m. The net plot size was 2.34 m² and spacing of 0.5 m and 1 m was maintained, respectively, between plots and replications. Quncho (Dz-CR-387) tef variety which is released by Debre Zeit Agricultural Research Center was used for the experiment.

2.3. Field management practices
The land preparation activities were taken according to farmers' practice in the area and leveling was carried out manually to ensure better seedbed for small seeds of tef. All Triple Super Phosphate and half of the Urea were applied at the time of sowing for row planting. The rest nitrogen fertilizer (Urea) was applied at the growth stage or tillering stage of the tef crop. This was due to reduce leaching loss of nutrients and harmonizing the supply with the crop demand. Additionally, management practices like weeding, watering, etc. were done alike to farmers’ practice in the area.

2.4. Soil sampling and analysis
A composite soil sample from the depth of 0–15 cm was taken independently of 10 representative spots. The soil physicochemical parameters were analyzed for this study. Soil organic matter was determined by following the Walkley and Black (1934) method. According to Kehinde et al. (2019). report soil pH was determined in a 1:2.5 soil: water ratio using a glass electrode attached to a digital pH meter (2015). Total N was determined by the Kjeldahl method (Frietal & Dewis, 1970).

Figure 1. The minimum and maximum temperature and mean rainfall of the experimental area during 2019-year periods (Source: Hawassa meteorological data station (2019)).
Available P was determined by Olsen et al. (1954) method. Soil cation exchange capacity was determined by using 1 M ammonium acetate.

### 2.5. Data collection and measurements

#### 2.5.1. Phenological growth parameters

- **Days to panicle emergence** were recorded as the number of days from seedling emergence to the time when the tips of panicles at least 10 first emerged from the main shoot in each plot.

- **Days to physiological maturity** were 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 light yellow color.

- **Plant height** was measured as the height of tef plants in centimeters from the base of the main stem to the tip of the panicle of tef and recorded as the total of 10 randomly selected tef 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 of tef crop as the average of 10 randomly chosen tef plants at physiological maturity.

#### 2.5.2. Yield and yield components

- **The number of effective tillers** was counted including the main shoot from an area of 10 randomly chosen tef plants from each plot.

- **1000-seed weight** was determined by taking 1000 seeds from each plot using a sensitive balance.

- **Grain yield** was calculated as the weight of the air-dried tef seeds harvested from the net plot area of each plot in a kilogram. For analysis, gram per plot was converted to a kilogram per hectare.

- **The straw yield** was measured by subtracting the grain yield of tef from the above-ground dry biomass yield of the crop.

- **Biomass yield** at harvesting maturity, the whole tef plant parts, including leaves and stems, and seeds from the net plot size were harvested and after drying, the biomass yield was recorded.

- **Harvest index** was measured as the ratio of grain yield to shoot biomass at harvest in kilogram from the net plot area.
2.6. Lodging percentage

The degree of lodging was assessed just before the time of harvesting by visual observation based on the scales of 1–5 (Asaye, 2017). Where 1 (0–15%) indicates no lodging and 5 (60–90%) indicates 100% lodging (Berry et al.). 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 (Wato, 2019; Bizuwork and Yibekal, 2020).

2.7. Statistical data analysis

The data were subjected to analysis of variance (ANOVA) procedures by using SAS version 9.4 with a general linear model procedure. Mean separation (mean differences comparison) was undertaken by the Least Significant Differences at a 5% level of probability.

3. Results and discussion

3.1. Days to 50% panicle emergence

The analysis of variance indicated that days to panicle emergence were significantly (P < 0.01) affected by nitrogen fertilizer rates (Table 2). Application of N rate at 90 Kg ha⁻¹ significantly delays panicle emergence than that of the other treatments (Table 2). Hence, the longest days (70.333 days) to panicle emergence were observed from 90 Kg N/ha while the shortest days (43.667 days) were recorded from the control plots. The lengthy in days to panicle emergence 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 in line with the findings of Haftamu et al. (2009), Wakene et al. (2014), and Wato (2019) reported that a significantly prolonged number of days to heading in response to N application in tef.

3.2. Days to physiological maturity

Days to 90% of maturity were significantly (P < 0.01) influenced by the main effects of the N rate (Table 2). Application of high-rate N delayed maturity in tef which was significant with the increase in nitrogen application rates (Table 2). Hence, it was postponed by 31 days in response to receiving 90 Kg N ha⁻¹ than that of the control treatment (Table 2). This might be attributed to the formation of chlorophyll which keeps the plant photosynthetically active for a longer period. This result incoherent with the findings of Fenta, 2018; Temesgen, 2001 found that high N application rates caused physiological maturity to delay due to the direct effect of N on vegetative growth in tef.

3.3. Plant height

Plant height was significantly (P < 0.01) affected by the main effects of N fertilizer rates (Table 2). The highest plant height (120.133 cm) was obtained with the application of 90 Kg N ha⁻¹ which was 56.163%, 34.9%, and 4.633% greater than the control, 30, and 60 Kg N/ha, respectively (Table 2).

### Table 2. Days to 50% panicle emergence, days to 90% physiological maturity, and plant height were influenced by N fertilizer rates

| Main Effect | PE  | PM  | PH   |
|-------------|-----|-----|------|
| N- rate (Kg/ha) |     |     |      |
| 0           | 43.667      | 91  | 63.97  |
| 30          | 50.333       | 101 | 85.233 |
| 60          | 61.667       | 112 | 115.5  |
| 90          | 70.333       | 122 | 120.133 |
| LSD         | 11.77        | 13.83 | 10.98  |
| CV (%)      | 10.43        | 6.51  | 5.71   |
2). This may be characterized that N usually favors vegetative growth of tef, happening in the higher status of the plants with the tallest plant height. Thus, the tef plants attained significantly maximum plant height with a further increase in the N application rate. In line with this result (Ekero et al., 2021; Haftamu et al., 2009; Okubay et al., 2014) described that tef with upper plant height was obtained by applying the maximum amount of nitrogen rate. Similarly, Fenta (2018) revealed that tef plants treated with higher rates of nitrogen (92 kg ha\(^{-1}\)) were taller (about 112.6 cm in mean height followed by 107.7 cm at 69 kg ha\(^{-1}\)) than the rest rates of nitrogen fertilizer.

LSD: Least Significant Differences; CV: Coefficient of Variance, PE: Panicle Emergence, PM: Physiological Maturity, PH: Plant Height. Means within the same column and the same treatment category followed by the same superscript letters are not significantly different as judged by LSD at \(P \leq 0.05\).

### 3.4. Panicle length

The analysis of variance indicated that the nitrogen rates were highly significantly \((P \leq 0.01)\) affected panicle length (Table 3). 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 tef. Thus, the maximum panicle length (42.667 cm) was recorded when 90 kg ha\(^{-1}\) N was applied which was 11.567%, 7.734%, and 6.7% higher than the control plots, 30, and 60 kg N ha\(^{-1}\), respectively (Table 3). Having a long panicle is directly related to the yield of tef. The increment in panicle length due to higher N application might be the better N position of the plant during the panicle development and growth period. Consistent with this result, Awan et al., 2011; Gebrelibanos & Dereje., 2015; Getahun et al., 2017 reported the highest panicle length found in treatments receiving higher nitrogen rates. Similarly, Ausiku et al. (2020) reported that treatments that received a high nitrogen rate (90 kg ha\(^{-1}\) increased the panicle length in pearl millet.

| Main Effect | PL | FT | TSW |
|-------------|----|----|-----|
| N-Rates (Kg/ha) |    |    |     |
| 0           | 31.1\(^c\) | 4.267\(^c\) | 0.23\(^c\) |
| 30          | 34.933\(^bc\) | 6.5\(^a\) | 0.29667\(^b\) |
| 60          | 35.967\(^ab\) | 8.733\(^b\) | 0.33\(^ab\) |
| 90          | 42.66 \(^a\) | 12.367\(^a\) | 0.37\(^a\) |
| LSD         | 6.71 | 3.41 | 0.055 |
| CV (%)      | 9.3 | 21.45 | 8.8 |

Table 3. Panicle length (cm), fertile tillers (no), and thousand seed weight (gm) were influenced by nitrogen fertilizer rates on tef

| Main Effect | BY | GY | SY |
|-------------|----|----|----|
| N-Rates (Kg/ha) |    |    |     |
| 0           | 5380 \(^c\) | 1356.7 \(^c\) | 5223.3 \(^c\) |
| 30          | 8500\(^b\) | 2303.3\(^b\) | 6963.3\(^b\) |
| 60          | 10670\(^ab\) | 2883.3\(^ab\) | 8453.3\(^ab\) |
| 90          | 12,026.7\(^a\) | 3200\(^a\) | 9060\(^a\) |
| LSD         | 2280 | 441.79 | 1281.9 |
| CV (%)      | 12.5 | 9.1 | 8.6 |

Table 4. Biomass yield (Kg/ha), grain yield (Kg/ha), and straw yield (Kg/ha) were affected by the nitrogen rates
3.5. Number of fertile tillers
The number of fertile tillers was significantly (P < 0.01) affected by N rate (Table 3). In the current study, it was found that with the successive increase in nitrogen fertilizer application rates, the number of fertile tillers also increased significantly. The maximum numbers of fertile tillers (12.367 no) were obtained with the application of 90 kg N ha⁻¹ which was higher by 8.1%, 5.867%, and 3.634%, over the control treatment, 30, and 60 kg N ha⁻¹, respectively (Table 3). This might be obtained due to the more availability of N that might have played a vital role in facilitating the growth and development of plants through cell division. Consistent with these results, Ekero et al., 2021; Fenta, 2018; Wato, 2019 reported a significantly maximum number of tillers in response to the application of a high N rate in teff. Likewise, Okubay et al. (2014) reported that the number of fertile tillers per plant increased linearly with an increasing rate of applied SRU from 9 in the plots without N (control) to 22.67 in the plots supplied with 69 kg N ha⁻¹.

3.6. Thousand seed weight
Thousand seed weights were significantly (P < 0.01) affected by the N rate (Table 3). This study indicated that the application of nitrogen rate influenced thousand seed weight. The highest thousand seed weight (0.37 gm) was recorded at an N rate of 90 Kg/ha and the lowest (0.23 gm) was recorded from the control plots (Table 3). The improvements 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, reduce with further application of N rate (Table 3). In line with this result, Ekero et al. (2021) found that the weight of 1000-grains was maximum when nitrogen was applied at a rate of 40 kg ha⁻¹ in teff. Similarly, Anjum et al. (2015) reported that the application of maximum N rate increased the 1000 seed weight in Mung bean.

LSD: Least Significant Differences; CV: Coefficient of Variance, PL: Panicle Length, FT: fertile Tillers, TSW: Thousand Seed Weight. Means followed by the same superscript letters are not significantly different as judged by LSD at P ≤ 0.05

3.7. Biomass yield
Biomass yield was significantly (P < 0.01) influenced by the main effects of the N rate (Table 4). The effect of N fertilizer rates was significantly affected by the biomass yield of teff. The highest biomass yield (12,026.7 kg) was attained from a 90 kg N ha⁻¹ application. While the lowest biomass (5380 kg) was obtained from the control treatment (Table 4). In general, the further increase in nitrogen fertilizer rate increased the biomass yield of teff. Similar results were reported by Serrano et al, 2000; Temesgen, 2001; Wato, 2019; they found that the highest biomass yield was obtained by applying high N ha⁻¹ in teff. The improvements in the ground biomass yield due to high nitrogen might be high nitrogen supply positively causes high vegetative growth and enlargement of stem cells that consequently increased biomass yield. Incoherent with the present finding, Kand and Nagarajan (2013) reported that an increase in biomass yield due to the high N fertilizer rate in Spirulina platensis.

| Main effects | LI | HI |
|--------------|----|----|
| N- Rate (Kg/ha) | | |
| 0            | 31<sup>c</sup> | 21.1667<sup>c</sup> |
| 30           | 36.4<sup>ab</sup> | 24.3067<sup>ab</sup> |
| 60           | 49.467<sup>ab</sup> | 24.7633<sup>a</sup> |
| 90           | 59.733<sup>a</sup> | 25.3367<sup>a</sup> |
| LSD          | 13.76 | 1.4861 |
| CV (%)       | 15.6 | 3.12 |
3.8. Grain yield
Grain yield was significantly (P < 0.01) affected by the main effects of Nitrogen rates (Table 4). Grain yield was highly significantly (P ≤ 0.01) affected by the main effects of nitrogen fertilizer rates. The highest grain yield (3200 Kg) was obtained from plants that were supplied with 90 kg N/ha and the lowest grain yield (1356.7 Kg) was obtained from control plots. Overall, a further increase in the application of nitrogen fertilizer rates increased the grain yield of tef. Increased grain yield due to increased N application was also reported for different cereal crops (Dubale, 2019).

In line with the present finding, Fresew et al. (2018) found that the highest grain yield was obtained in response to the application of 360 kg N ha⁻¹ in three splits of ¼ at sowing, ¼ at tillering, and ¼ at booting, which was in statistical parity with the grain yield obtained in response to the application of 240 kg N ha⁻¹ ⅓ at sowing, ⅓ at tillering and ⅓ at booting. Generally, nitrogen fertilizer application has a significant effect on the chlorophyll concentration, leaf area index of plants, canopy interception, as well as other biophysical characteristics of plants.

3.9. Straw yield
The straw yield was affected significantly (P < 0.01) by the main effects of N rates (Table 4). The highest straw yield (9060 Kg) was attained from plants that were supplied with 90 kg N ha⁻¹ while the lowest straw yield (5223.3 Kg) was obtained from the control treatment (Table 4). Similar to the results of this study, Rahman et al. (2000) and Wato (2019) reported that nitrogen influenced vegetative growth in terms of plant height and number of tillers (Tables 2 and 3) which resulted in increased straw yield (Table 4).

The increase in straw yield in response to the application of high N fertilizer might be due to greater availability and uptake of the nutrient by plants, and the resulting induction of vigorous vegetative growth with more leaf area, this resulting in higher photosynthesis and assimilates production and dry matter accumulation (Islam et al., 2008; Wato, 2019). Similarly, Tewolde et al. (2020) found that the highest straw yield was obtained in response to applying 250 kg ha⁻¹ which is higher by about 80 and 44.4% as compared to the teff straw yield obtained in response to the unfertilized plot and the plot received the blanket fertilizer recommendation (46 N and 46 P₂O₅ kg ha⁻¹).

LSD: Least Significant Differences; CV: Coefficient of Variance, BY: Biomass Yield, GY: Grain Yield; SY: Straw Yield. Means within the same column and the same treatment category followed by the same superscript letters are not significantly different as judged by LSD at P ≤ 0.05

3.10. Lodging index
The main effects of the nitrogen fertilizer rate were significantly (P < 0.01) influenced the lodging index (Table 5). The highest lodging index (59.733%) was obtained from plants supplied with 90 kg N ha⁻¹ and the lowest (31%) was obtained from the control (Table 5). In general, a further increase in N application rates increased the lodging index of tef. This could be due to the profound effect of high N supply on increasing vegetative growth thereby leading to bending of the weak stem of the plant due to the sheer load of the canopy. Similarly, Temesgen, 2001; Tesfahun, 2018 obtained significant differences in the lodging percentage of tef due to N application. Incoherent with these finding Ekero et al. (2021) reported that the maximum result of lodging percentage was recorded from 50 kg/ha NPSB (30.50%) and the minimum was recorded from 0 kg/ha NPSB (28.25%).

3.11. Harvest index
The harvest index was significantly (P < 0.01) affected by the effects of the nitrogen fertilizer rate (Table 5). The maximum harvest index (25.34%) was obtained from plants that supplied 90 Kg N/ha. However, there was no statistical difference among plants that supplied 60 Kg N/ha (Table 5). The lowest harvest index (21.1667%) was obtained from the control. plants that supplied nitrogen at 97.5 kg ha⁻¹ (Table 5). In general, an increase in the N fertilizer rates increased the harvest index. In line with the present study, Bızıuwork and Yibekal (2020) explained the highest HI (47%) was obtained at the application of 46 kg N ha⁻¹ whereas the lowest HI (32%) was produced from the application of 115 kg N ha⁻¹. This finding was contrary to those of Mahato et al., 2007 who obtained a higher harvest index in crops with more or less increased nitrogen application rates and decreased finally with further increase in the application of...
nitrogen fertilizer. Generally, the supply of N fertilizer rates beyond 60 kg/ha cannot be intended to increase in the mean harvest index (Table 5).

LSD: Least Significant Differences; CV: Coefficient of Variance; LI: Lodging Index; HI: Harvest Index. Means within the same column and the same treatment category followed by the same superscript letters are not significantly different as judged by LSD at P ≤ 0.05

4. Conclusions

The application of nitrogen fertilizer rates was significantly influenced most of the plant phenology, growth parameters, yield, and yield components of teff. Thus, the highest application (90 Kg N/ha) showed to be superior to the dose of the other concerning boosting most of these attributes/characters of the teff. In this view, the study revealed that the teff crop responded more to N fertilization. This shows that 90 Kg N/ha should be employed to increase the productivity of the crop rather than using 60 Kg N/ha currently used in the study area.

Therefore, considering the finding of the present study, it may be tentatively concluded that farmers in the Hadiya Zone may apply 90 Kg N ha⁻¹ 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 for the recommendation of the appropriate N dose on teff.

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