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# Comparative Evaluation of Transplanting and Sowing on Growth and Yield of Tef (*Eragrostis tef* (Zucc.)) at Jimma and Buno Bedele South Western Ethiopia

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**Abstract:** Field experiments were conducted for four consecutive years (2013-2016) under rain-fed conditions in South Western part of Ethiopia, to evaluate the time of transplanting and direct planting of different seed rates either in row or broadcast for improving growth and yield of tef. The experiment had two time of transplanting tef seedling (at 10 and 20 ahead of planting); five tef seed rates (5, 10, 15, 20, 25 kg ha$^{-1}$) planted in rows and two tef seed rates (5 and 25 kg ha$^{-1}$) planted in broadcasting. The experiment was designed in a randomized complete block design with three replications. Over year and locations mean results revealed that all parameters (number of tiller per plant, plant height, Panicle length, lodging percent, grain yield, aboveground biomass, straw yield and harvest index) were significantly affected by different planting methods (transplanting, row planting and broadcasting) and seed rates. Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time gave the highest number of tillers per plant, plant height, panicle length, grain yield, straw yield and above ground biomass. Whereas, the lowest seed rate 5 kg ha$^{-1}$ with both broadcasting and row planting gave the lowest grain yield, straw yield, above ground biomass and also lodging percent. Broadcast seeds at the rate of 25 kg ha$^{-1}$ gave the lowest number of tillers per plant, plant height and panicle length and gave the highest lodging percent. These results indicated as the seed rate increases the problem of lodging of tef increases. The Partial budget analysis revealed that the higher net benefit and higher marginal rate of return were obtained from drill seeds in rows of 20 cm apart at the rate of 10 kg ha$^{-1}$ and broadcast seed at rate of 25 kg ha$^{-1}$ with values of 4004% and 3351%, respectively. This is, therefore, drill seeds in rows of 20 cm apart at the rate of 10 kg ha$^{-1}$ and broadcast seed at rate of 25 kg ha$^{-1}$ can be used to high and economic yield of tef at South Western parts of Ethiopia.

**Keywords:** Transplanting, Row Spacing, Seed Rate, Tef, Yield

## 1. Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] has the largest value in terms of both production and consumption in Ethiopia [1, 2]. The national productivity of tef is very low at around 1.8 tone ha$^{-1}$ CSA (Central Statistical Agency) [3] with the highest productivity farmers achieving 2.5 ton ha$^{-1}$ and research field trials of tef reaching 4-5 ton ha$^{-1}$ [4]. Tef in Ethiopia stands 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 [5].

At Oromiya regional state the average yield was 1.37 ton ha$^{-1}$ and it is below the average yield of the country which was 1.56 ton ha$^{-1}$ CSA [6] and recently it has been argued that the traditional sowing technology is a major constraint to increased tef productivity [7]. The cause for lower productivity is lodging, method of planting and fertilizer application. Mean time the combined effect of those factors result up to 22% reduction in grain and straw yield [8].

Seed rate is the most important agronomic aspect which needs due attention. According to Wubante and Menzir [9], when the plant density exceeds an optimum level, competition among plants for light above ground, water and nutrients below ground becomes severe. Consequently, plant growth slows down and the grain yield decreases. Melaku [10] explains that there was significance difference increase in yield components of tef with decreasing seed rate from highest to lowest.

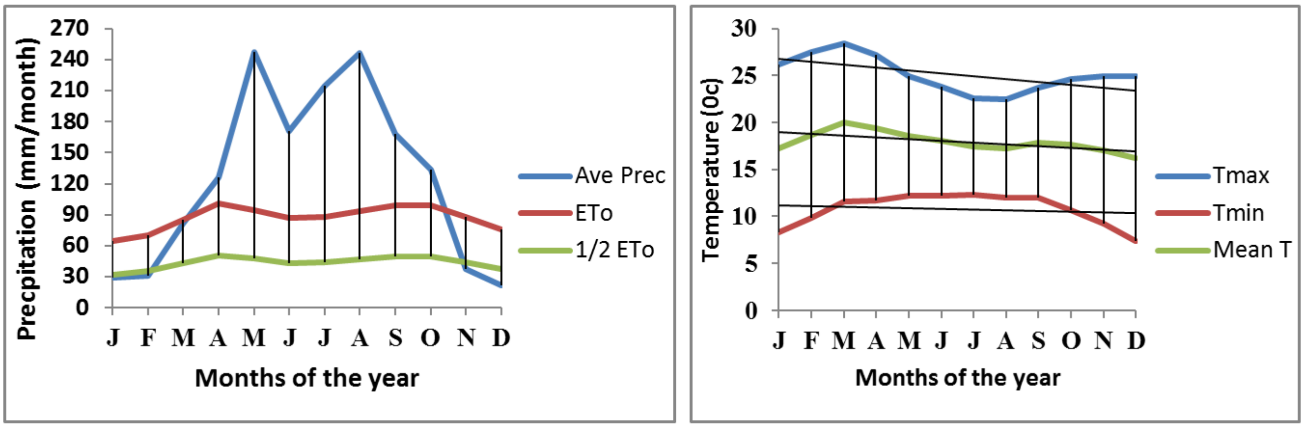
Broadcasting is the major tef planting method in Ethiopia. However, transplanting is the major means of planting cereals like rice used in other parts of the world [11]. Patel and Charugamba [12] stated that transplanted seedlings e.g. in rice it is capable of yielding 30% more than broadcasted rice. The other advantage of transplanting is effective utilization of rainy season and faster maturity of crops particularly inrain-fed ecosystems since the crop partly passes some of its growth stage in nursery [13]. As compared to broadcasted, transplanted crops competes better with weeds [11].

Labor intensiveness at the time of planting is the only drawback of transplanting compared to direct seeding [11]. Ages of seedlings, spacing and number of seedlings per hill during transplanting are among the major factors that determine the extent of the system's advantage [14, 11]. To improve the yield and quality tef, seedlings need to be transplanted at their optimum age. Hence, this paper was initiated to evaluate the time of transplanting and direct planting of different seed rates either in row orbroadcast for improving growth and yield of tef.

## 2. Materials and Methods

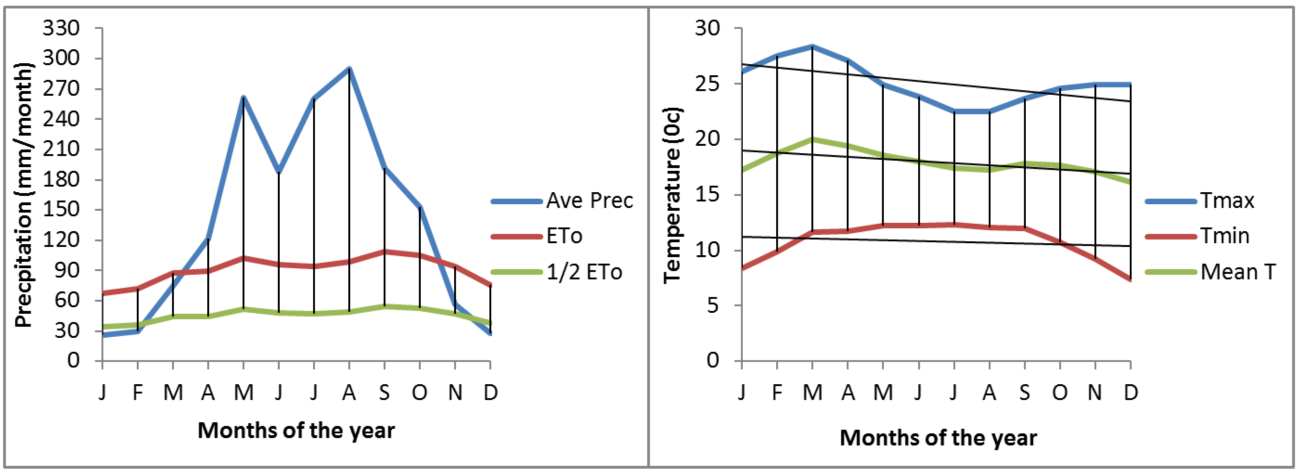
### *2.1. Description of the Study Areas*

The field experiments were performed on farmers' fields at Tiroafetawareda of Jimma Zone and Banshurekebele of Buno Bedele zone, South Western Ethiopia for four consecutive years (2013-2016) main cropping seasons planted at mid July to end of July. The farming system of the both study sites were cereal crops dominated with maize, tef and sorghum. It has warm and cold climate, also convenient topography which is very suitable for all agricultural practices. The soil type of the experimental sites was Eutric-nitisols (reddish brown). Monthly total rainfall and average minimum and maximum temperature of Tiroafeta and Bedele over 4 years study periods were presented in Figures 1 and 2, respectively.




Source: KNMI Climate data explorer.

***Figure 1.*** *Four year time scale (2013-2016) of Precipitation, ETo, 1/2 ETo, maximum and minimum temperature at Jimma, Tiroafetaworeda.*




Source: KNMI Climate data explorer.

***Figure 2.*** *Four year time scale (2013-2016) of Precipitation, ETo, 1/2 ETo, maximum and minimum temperature at Buno Bedele (Banshure district).*

### 2.2. Soil Physico-chemical Properties

Experimental field soils were characterized for selected physico-chemical properties before the application of the treatments (Table 1). Soil pH of Tiroafeta and Bedele were 5.29 and 5.11 respectively, which was strongly acidic [15] and ideal for the production of most field crops. The pH of the soil affects crop growth by suppressing the root development and reducing availability of macronutrients to plants especially phosphorus [16]. The soil total N for Tiroafeta was 0.27%, where as for Bedele it was 0.24% which found to be high and medium respectively for crop growth and development [17]. At Tiroafeta and Bedele the organic carbon content of the soil was 2.71% and 2.62%respectively, whereas the Bray II extractable available Phosphorous was 1.99 mg $kg^{-1}$ and 1.91 mg $kg^{-1}$ respectively which was below the critical level (8 mg $kg^{-1}$) for most crop plants as described by Tekalign and Haque [18] (Table 1).

***Table 1.** Selected physico-chemical properties of the soil of the experimental sites before planting.*

| Soil characters | Tiro Afeta | | Bedele | | Method of analysis |
|---|---|---|---|---|---|
| | Values | Rating | Values | Rating | |
| pH (1:2.5) | 5.29 | Strongly acidic | 5.11 | Strongly acidic | 1:2.5 ratio water method |
| Av P (mg $kg^{-1}$) | 1.99 | Low | 1.91 | Low | Bray II method |
| TN (%) | 0.27 | High | 0.24 | Medium | Kjeldahl method |
| OC (%) | 2.71 | Low | 2.62 | Low | Walkley and Black method |
| C:N ratio | 10.0 | Medium | 10.9 | Medium | |
| OM (%) | 4.66 | Medium | 4.51 | Medium | |

*Where pH= Hydrogen ion concentration, OC=Organic Carbon, TN=Total Nitrogen, Av. P=Available Phosphorous, OM=Organic Matter. Values are the means of duplicated samples.

### 2.3. Experimental Treatments and Procedures

A field experiment that compared transplanting time and direct seeding of tef at different seed rate was conducted in major tef growing woredas (Bedele and Tiroafeta) of southwestern part of the country. The tef was planted during end of July and harvested early November of each year. The experiment was laid out in RCBD with three replications. A plot of size 5 m x 4 m was used. Seeds were drilled in 20 cm rows apart for row planted and also for transplanted tef. Tef variety Kuncho was used in the experiment. Urea (46% N) at a rate of 100 kg $ha^{-1}$ and DAP (18% N, 46% $P_2O_5$) fertilizer at rate of 100 kg $ha^{-1}$ were used as a source of nitrogen, and phosphorus, respectively. Full dose of DAP was applied at planting, while urea fertilizer (N in DAP was deducted) was applied 30 days after emergency. All other cultural practices were done based on available recommendations for tef in Southwestern part of the country.

Thus, the following nine treatments were evaluated:

T1: Grown at nursery for 10 days ahead of planting, then transplanted to plots at sowing time T2: Grown at nursery for 20 days ahead of planting, then transplanted to plots at sowing time T3: Drill seeds in rows of 20 cm apart at the rate of 5 kg $ha^{-1}$

T4: Drill seeds in rows of 20 cm apart at the rate of 10 kg $ha^{-1}$

T5: Drill seeds in rows of 20 cm apart at the rate of 15 kg $ha^{-1}$

T6: Drill seeds in rows of 20 cm apart at the rate of 20 kg $ha^{-1}$

T7: Drill seeds in rows of 20 cm apart at the rate of 25 kg $ha^{-1}$

T8: Broadcast seeds at the rate of 25 kg $ha^{-1}$

T9: Broadcast seeds at the rate of 5 kg $ha^{-1}$

### 2.4. Data Collected

#### 2.4.1. Panicle Length (cm)

IT was measured from the node where the first panicle branch starts to the tip of a panicle.

#### 2.4.2. Number of Tillers Per Plant

It was determined by counting the number of additional plants growing from the main stem.

#### 2.4.3. Plant Height (cm)

It was recorded from five random plants at maturity by measuring the height from ground to the tip of the panicle.

#### 2.4.4. Lodging (%)

Lodging percentage was recorded at the time of harvest from each plot.

#### 2.4.5. Straw Yield (kg $ha^{-1}$)

Was measured by subtracting grain yield per plot from the total above ground biomass.

#### 2.4.6. Above Ground Biomass Yield (kg $ha^{-1}$)

Was weighted by drying in sunlight still a constant dry weight was attained.

#### 2.4.7. Grain Yield (kg $ha^{-1}$)

It was measured after threshing the grains harvested from each plot.

#### 2.4.8. Harvest Index

It was calculated as the ratio of grain yield to above ground biomass yield on dry weight basis [19]. $HI(\%) = \frac{\text{Economic yield (kg/ha)}}{\text{Total biological yield (kg/ha)}} x100$

### 2.5. Data Analysis

The data were subjected to combined analysis of variance (ANOVA) over years after confirmation of homogeneity of error variance using SAS software program version 9.3. Over location combined analyses were conducted because of homogeneity of error variance. For the treatments that showed significant differences, the means were compared using least significant difference.

### *2.6. Partial Budget Analysis*

The partial budget analysis was done through technique described by CIMMYT [20]. The partial budget analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested. All costs and benefits were calculated on a per hectare basis in Ethiopian Birr (ETB). The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment, the gross field benefit (GFB) $ha^{-1}$ (i.e., the product of field price and the mean yield for each treatment), cost of labor during planting and the total costs that varied (TVC).

The net benefit (NB) was calculated as the difference between the GFB and the TVC. A minimum acceptable marginal rate of return (MRR) of 100% was used. The dominance analysis procedure as detailed in CIMMYT [20] was used to select potentially profitable treatments from the range that was tested. Sensitivity analysis for different interventions was also carried out to test the recommendation made for its ability to withstand price changes. Through sensitivity analysis, maximum acceptable field price of an input was calculated with the minimum rate of return as described by Shah *et al*. [21].

## 3. Results and Discussions

The homogeneity test of the error variances over location indicated that the error variance was homogenous and hence combined analysis of variance was conducted. The year and the treatment difference showed highly significant ($P \leq 0.01$) effect on all parameters i.e. number of tiller per plant, plant height, Panicle length, lodging percent, grain yield, aboveground biomass, straw yield and harvest index. Over location analysis indicated highly significant ($P \leq 0.01$) effect on plant height, grain yield and harvest index whereas non-significant effect ($P>0.05$) on number of tiller per plant, Panicle length, lodging percent, aboveground biomass and straw yield (Table 2).

***Table 2.*** *Mean square from combined analysis of transplanting time and sowing method on growth, yield attribute and yield of tef during 2013- 2016 cropping seasons at Tiroafeta and Buno Bedele southwestern Ethiopia.*

| Parameter | Mean square for source of variation | | | | |
|---|---|---|---|---|---|
| | Year (3) | Location (1) | Replication (2) | Treatment (8) | Error a (16) |
| Number of tillers per plant | 417.96** | 0.296 ns | 3.95 ns | 52.92** | 3.24 |
| Plant height (cm) | 2561.70** | 644.12** | 76.22 ns | 337.77** | 88.92 |
| Panicle length (cm) | 17193.54** | 86.39 ns | 37.28 ns | 106.85** | 29.41 |
| Lodging % | 31682.20** | 140.17 ns | 119.68 ns | 897.25** | 204.04 |
| Grain yield (kg $ha^{-1}$) | 3908266.84** | 578927.34** | 16849.22 ns | 381777.8** | 86994.56 |
| Straw yield (kg $ha^{-1}$) | 86655788.6** | 571856.5 ns | 424520.7 ns | 1972631.4** | 710861.1 |
| AGB (kg $ha^{-1}$) | 124269670.7** | 2543674.1 ns | 621982.8 ns | 3455752.9** | 1120295.3 |
| Harvest index | 0.084** | 0.023** | 0.00044 ns | 0.0053** | 0.0014 |

Numbers in parenthesis = Degrees of freedom; *= Significant ($P \leq 0.05$); ** =Highly significant ($p \leq 0.01$) difference; Ns=Non-significant; AGB= Above ground biomass; Ha = Hectare.

### *3.1. Plant Height*

The significant highest plant height (133.9 cm) was recorded during 2013 cropping season which was statically at par with 2016 cropping season whereas, the lowest plant height (120.7 cm) was recorded during 2014 cropping season and it was statistically at par with 2015 cropping season (Table 3). Regarding over location difference the significant highest plant height (129.7 cm) was recorded at Tiro Afeta whereas, at Bedele the lowest plant height (126.2 cm) was recorded (Figure 3).

The mean significant higher plant height (134.0 cm) was recorded from Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time whereas the lowest plant height (121 cm) was recorded from broadcasting seeds at the rate of 25 kg $ha^{-1}$ (Table 4). These results indicated the transplanted tef seedling gave the highest plant height and the highest seed rate gave the lowest plant height. The plant height was increased by 10.7% at transplanting tef seedling that raised in nursery for 10 days as compared to the seed broadcasting at the rate of 25 kg $ha^{-1}$. Highest plant height in tef seedling transplanting might be due to less intra-specific competition of plants for light and other growth resources such as nutrients and soil moisture [22].

### *3.2. Panicle Length*

The significant longest panicle length (84.4 cm) was recorded during cropping season of 2016, whereas the shortest panicle length (48 cm) was recorded during 2014 cropping season (Table 3). Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time was gave the highest panicle height (67.8 cm), whereas the lowest panicle length (61.2 cm) recorded from broadcasting seed at 25 kg $ha^{-1}$ (Table 4). Planting in row and transplanting increased the panicle length than seed broadcasting (at both seed rate of 5 and 25 kg $ha^{-1}$). The increment of panicle length in the case of row planting and transplanting might be resulted due to the utilization of more growth resources by decreasing competition among plants.

### *3.3. Number of Tillers Per Plant*

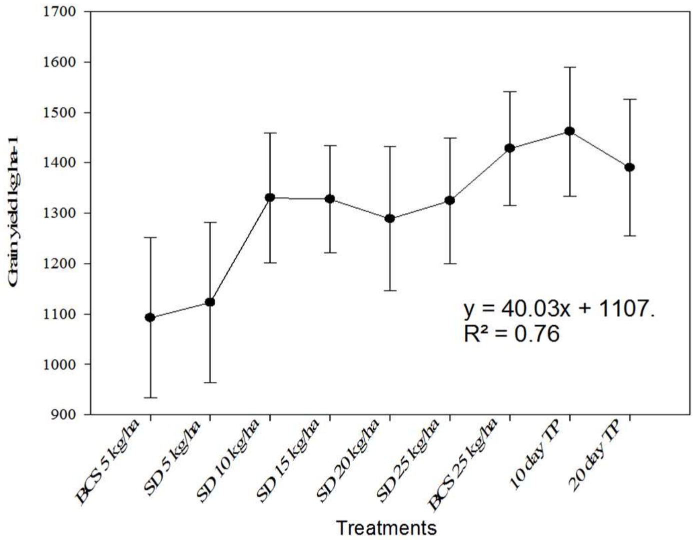
The highest number of tillers per plant was recorded during 2016 cropping season and the lowest was recorded at 2013 and 2014 cropping seasons (Table 3). Both transplanting times gave the highest number of tillers per plant (7.3-8.3), whereas broadcast seeds at the rate of 5 and 25 kg ha$^{-1}$ gave the lowest number of tillers per plant (3.9-4.3) (Table 4). Number of tillers per plant was increased by 41-53% when transplanting than when broadcasting. These might be due to the even distribution of seedlings in rows and good management is important to the wise use of nutrients, moisture, and aeration. As the population increased competition for a resource also increased and results for less tillering [23]. The current study in line with Abraham [24] who reported that the row sowing method had significantly more numerous total tillers than plants under broadcasting.

### *3.4. Lodging Percent*

The main problem of tef is the highest lodging percentage. The significant highest lodging percent (74%) was observed during 2015 cropping season and the lowest lodging percent (18.0%) was recorded a 2014 cropping season (Table 3). The highest lodging percent (53.1% and 50.8%) was recorded from broadcasting seed at the rate of 25 kg ha$^{-1}$ and from seedling transplanting 10 days ahead of planting respectively, and the lowest lodging percent (35.4 and 40.5%) was recorded from the lowest seed rate of 5 kg ha$^{-1}$ at both broadcasting and in row planting respectively (Table 4). The lodging percent was increased by 30% at highest seed broadcast rate of 25 kg ha$^{-1}$ then at the lowest seed broadcast rate of 5 kg ha$^{-1}$. These results indicated lodging percentage of the crop was increased by increasing the seed rate. Using of optimum seed rate allows boosting production and productivity of tef through reducing of lodging percent [25]. The significant difference in lodging between methods of sowing might beattributed from heavy panicle that bears by culm of the plant particularly for the transplanting method. These results are strengthened by Awan [26] who observed that transplanted plant was lodged due heavy panicles and high plant height.

### *3.5. Grain Yield*

Over season highest grain yield (1551.6 kg ha$^{-1}$) was recorded during 2016 cropping year whereas the lowest grain yield (926.4 kg ha$^{-1}$) was recorded during 2014 cropping year (Table 3). Over location mean indicated that the highest grain yield (1359 kg ha$^{-1}$) was recorded at Bedele than at Tiroafeta (1256 kg ha$^{-1}$) (Figure 2C). Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time gave the highest grain yield 1462 kg ha$^{-1}$ while broadcasting seeds at the rate of 5 kg ha$^{-1}$ gave the lowest grain yield of 1092 kg ha$^{-1}$ (Table 4). The result indicated the lowest seed rate of 5 kg ha$^{-1}$ either planted in row or broadcast gave the lower grain yields. Transplanting in a row considerably increased the seed yield compared to the broadcasting method (Figure 2). The grain yield of the tef was increased by 33.9% at seedling grown 10 days ahead of transplanting as compared to the lowest seed rate 5 kg ha$^{-1}$ planted in broadcast. The main effect of transplanting is increasing tiller number, producing strong and fertile tiller culms, increasing the number of productive tillers. Practically, the lower seed rate on small scale farming had a draw back in establishing of seedling with erratic rain fail; unless, there is development of tef planter. The reasons for higher yield in transplanting compared to other planting methods may be attributed to optimum plant population, increased tillering capacity of the plant, a greater number of productive tillers and higher number of seeds per panicle. This finding is in line with Tarekeet *et al.,* [27] who reported that transplanting increased grain yield by increasing productive tillers.




transplanting increased grain yield by increasing productive tillers.

*BSC=Broadcast seed; SD= Seed drill; TP=transplant.

***Figure 3.*** *Tef grain yields as a function of transplanting time and sowing method over the years and locations.*

### *3.6. Straw Yield*

The straw yield is the main output of the tef crop and farmers use it for animal feed. The highest straw yield (5175.5 kg ha$^{-1}$) was recorded during 2013 cropping season and the lowest (2221.4 kg ha$^{-1}$) was recorded at 2014 cropping season (Table). Regarding the sowing methods and seed rate of tef, the highest straw yield (4391 kg ha$^{-1}$) was recorded from transplanted seedling that grown for 10 days ahead of planting, whereas the lowest straw yield (3655 and 3661 kg ha$^{-1}$) was recorded from the lowest seed rate of 5 kg ha$^{-1}$ from both drilling in a rows and broadcast respectively (Table). It was increased by 20% by transplanting the tef then planting 5 kg ha$^{-1}$ seed rate. The result showed that straw yield was increased by increasing seed rate due to high plant height, number of tillers per plant and panicle length. These results are also strengthened by there port of Tareke [7] who got higher number of productive tillers and heavy panicle bearing culms, which contributed to increase in straw yield. Other studies on rice indicate that transplanting method of planting increased straw yields compared to row method [28].

### *3.7. Aboveground Biomass Yield*

The highest aboveground biomass (5853 kg ha$^{-1}$) was observed during 2013 cropping season whereas the lowest was recorded at 2014 cropping season (Table 3). The seedlings raised in nursery for 10 days ahead of planting gave the highest aboveground biomass, while lowest seed rate i.e. 5 kg ha$^{-1}$ both row planting and broadcasting gave the lowest aboveground biomass 4778 and 4801 kg ha$^{-1}$ respectively (Table 5).

The result indicates that as seed rate increases the above ground biomass increased and vice versa. The above ground biomass increased by 22.5% by transplanting seedling 10 days ahead of planting then row planting at the rate of 5 kg ha$^{-1}$. The result showed that aboveground biomass was increased by increasing seed rate and by transplanting due to high grain yield, straw yield, plant height, number of tillers per plant and panicle length. These results were in agreement with Alemu *et al.,* [29] that the increase in biomass yield is due secondary branch and leaf number and size which were grown during grain filling period beside panicle length and plant height. These results are also strengthened by the report of Tareke [7] who got higher number of productive tillers and heavy panicle bearing culms, which contributed to increase biomass. Other studies on rice indicate that transplanting method of planting increased biomass yields compared to row method [28].

***Table 3.*** *Evaluation of transplanting time and sowing method on growth, yield and yield components of tef at Jimma and Buno Bedelezone during 2013- 2016 cropping season.*

| Year | No. tiller per plant | Plant height (cm) | Panicle length (cm) | Lodging % | Grain yield (kg ha$^{-1}$) | Straw yield (kg ha$^{-1}$) | AGB kg ha$^{-1}$ | HI |
|---|---|---|---|---|---|---|---|---|
| 2013 | 3.13$^{c}$ | 133.9$^{a}$ | 50.4$^{c}$ | 61.9$^{b}$ | 1414.2$^{b}$ | 5175.5$^{a}$ | 6589.7$^{a}$ | 0.21$^{d}$ |
| 2014 | 3.09$^{c}$ | 120.7$^{b}$ | 48.0$^{d}$ | 18.0$^{d}$ | 926.4$^{c}$ | 2221.4$^{c}$ | 3147.7$^{d}$ | 0.31$^{a}$ |
| 2015 | 6.00$^{b}$ | 123.4$^{b}$ | 74.0$^{b}$ | 70.9$^{a}$ | 1337.5$^{b}$ | 4255.4$^{b}$ | 5592.6$^{c}$ | 0.24$^{c}$ |
| 2016 | 8.93$^{a}$ | 133.7$^{a}$ | 84.4$^{a}$ | 35.9$^{c}$ | 1551.6$^{a}$ | 4454.3$^{b}$ | 6027.0$^{b}$ | 0.26$^{b}$ |
| LSD (0.05) | 0.683 | 3.578 | 2.058 | 5.42 | 111.93 | 319.95 | 401.66 | 0.014 |
| F-test | ** | ** | ** | ** | ** | ** | ** | ** |

LSD= Least Significant Difference; CV=Coefficient of Variation; NS=Non significant; HI= Harvest Index; AGB=Above Ground Biomass; Values followed by the same letter within a column are not significantly different at P< 0.05.

***Table 4.*** *Evaluation of transplanting time and sowing method on growth parameters of tef.*

| Treatment | Number of tillers/plant | Plant height (cm) | Panicle length (cm) | Lodging (%) |
|---|---|---|---|---|
| Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time | 8.3$^{a}$ | 134.0$^{a}$ | 67.8$^{a}$ | 50.8$^{abc}$ |
| Seedlings raised in nursery for 20 days ahead of planting then transplanted to plots at sowing time | 7.3$^{a}$ | 129.7$^{abc}$ | 65.0$^{ab}$ | 43.3$^{cde}$ |
| Drill seeds in rows at the rate of 5 kg ha-1 | 4.7$^{bc}$ | 131.1$^{ab}$ | 64.5$^{bc}$ | 40.5$^{de}$ |
| Drill seeds in rows at the rate of 10 kg ha-1 | 4.9$^{b}$ | 126.1$^{bcd}$ | 63.3$^{bcd}$ | 44.4$^{bcd}$ |
| Drill seeds in rows at the rate of 15 kg ha-1 | 4.5$^{bc}$ | 130.0$^{abc}$ | 65.9$^{ab}$ | 49.2$^{abc}$ |
| Drill seeds in rows at the rate of 20 kg ha-1 | 5.1$^{b}$ | 125.5$^{cd}$ | 63.0$^{bcd}$ | 52.1$^{ab}$ |
| Drill seeds in rows at the rate of 25 kg ha-1 | 4.5$^{bc}$ | 127.3$^{bc}$ | 65.2$^{ab}$ | 51.5$^{abc}$ |
| Broadcast seeds at the rate of 25 kg ha-1 | 3.9$^{c}$ | 121.0$^{d}$ | 61.2$^{d}$ | 53.1$^{a}$ |
| Broadcast seeds at the rate of 5 kg ha-1 | 4.3$^{bc}$ | 126.8$^{bc}$ | 61.7$^{cd}$ | 35.4$^{e}$ |
| LSD<0.05 | 1.024 | 5.37 | 3.09 | 8.13 |
| CV | 34.03 | 7.38 | 8.45 | 30.59 |
| F test | ** | ** | ** | ** |

### *3.8. Harvest Index*

Harvest index is an indicator of dry matter partitioning towards the reproductive organs. During 2014 cropping season the significant highest harvest index was obtained, while the least harvest index was recorded during 2013 cropping season (Table 3). Over location mean indicated that the highest harvest index was obtained at Bedele than at Tiroafeta (Figure 3). Drilling seeds in rows at the rate of 10 kg $ha^{-1}$ was gave the highest harvest index (27.8) while drilling seeds in row at the rate of 25 kg $ha^{-1}$ gave the lowest harvest index (23.7) (Table 5). The lowest seed rate 5 kg $ha^{-1}$ in both sowing method and drilling seeds in the rate of 15, 20 and 25 kg $ha^{-1}$ gave the lowest harvest index. Transplanting takes an advantage in increasing harvesting index, which might help the plant to utilize growth resources (including solar radiation) in a better way to enhance fertile tiller numbers produce high grain yield. These results were in line with the result of Wakjira [30] who reported that transplanting increases harvest index in tef.

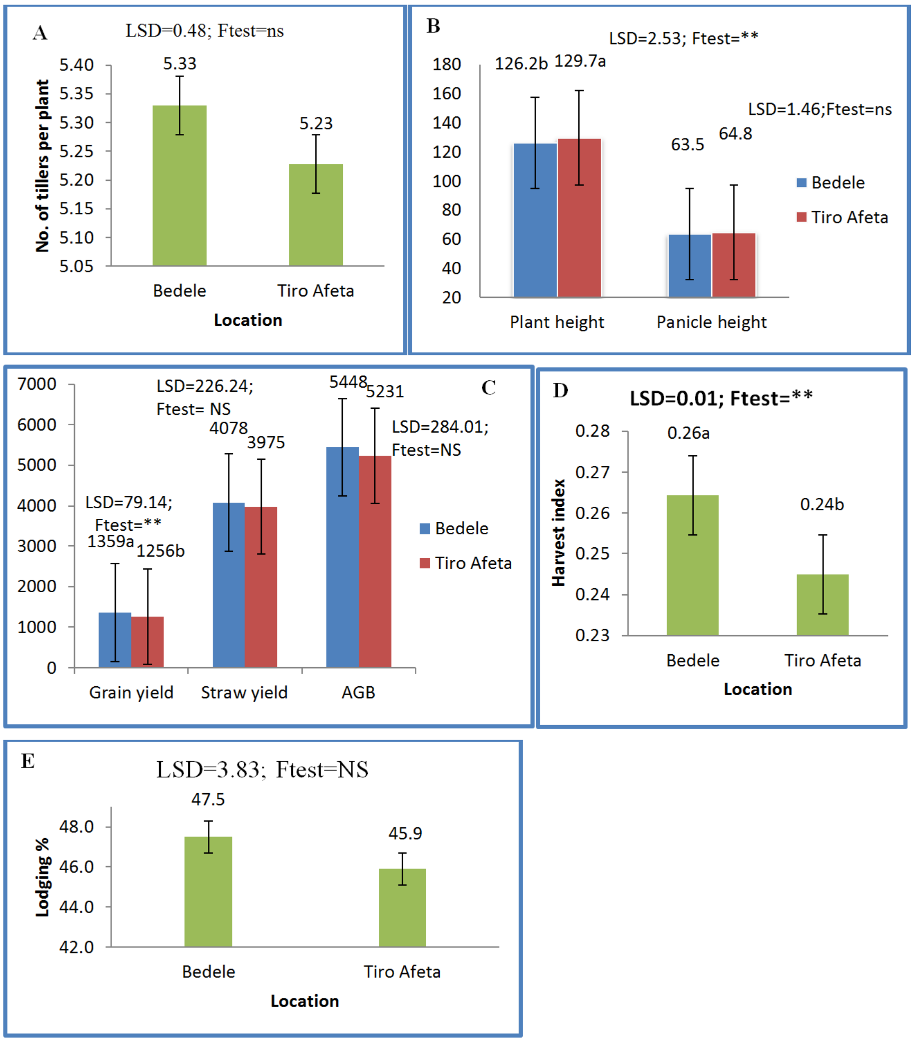



***Figure 4.*** *Evaluation of planting methods on number of tiller per plant (A), panicle height and plant height (B), grain yield, straw yield and above ground biomass yield (C), harvest index (D) and lodging percent (E) of tef at Tiroafeta and Buno Bedele.*

***Table 5.*** *Evaluation of transplanting time and sowing method on yield and yield components of tef.*

| Treatment | Grain yield (kg $ha^{-1}$) | Straw yield (kg $ha^{-1}$) | Above ground biomass (kg $ha^{-1}$) | Harvest index |
|---|---|---|---|---|
| Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time | $1462^{a}$ | $4391^{a}$ | $5853^{a}$ | $26.0^{abc}$ |
| Seedlings raised in nursery for 20 days ahead of planting then transplanted to plots at sowing time | $1390^{ab}$ | $3788^{cd}$ | $5178^{bcd}$ | $27.4^{a}$ |
| Drill seeds in rows at the rate of 5 kg $ha^{-1}$ | $1123^{cd}$ | $3655^{d}$ | $4778^{d}$ | $24.4^{bcd}$ |
| Drill seeds in rows at the rate of 10 kg $ha^{-1}$ | $1330^{ab}$ | $3896^{bcd}$ | $5227^{bcd}$ | $27.8^{a}$ |
| Drill seeds in rows at the rate of 15 kg $ha^{-1}$ | $1328^{ab}$ | $4169^{abc}$ | $5497^{ab}$ | $24.8^{bcd}$ |
| Drill seeds in rows at the rate of 20 kg $ha^{-1}$ | $1289^{bc}$ | $4099^{abcd}$ | $5387^{abc}$ | $24.5^{bcd}$ |
| Drill seeds in rows at the rate of 25 kg $ha^{-1}$ | $1325^{ab}$ | $4374^{ab}$ | $5698^{ab}$ | $23.7^{d}$ |
| Broadcast seeds at the rate of 25 kg $ha^{-1}$ | $1428^{ab}$ | $4207^{abc}$ | $5635^{ab}$ | $26.4^{ab}$ |
| Broadcast seeds at the rate of 5 kg $ha^{-1}$ | $1092^{d}$ | $3661^{d}$ | $4801^{cd}$ | $24.2^{cd}$ |
| LSD<0.05 | 167.89 | 479.92 | 602.49 | 2.11 |
| CV | 22.56 | 20.94 | 19.82 | 14.64 |
| F test | ** | ** | ** | ** |

### *3.9. Correlation Analysis*

Stepwise multiple linear correlation analyses were carried out using treatment means to determine the effects of method of sowing and seeding rates on the grain yield. Generally, the positive correlation of grain yield with all the agronomic parameters was observed except with the plant height. Grain yield of tef was significant and positively correlated with number of tiller per plant (r = 0.41**), panicle height (r = 0.41**), lodging percent (r=0.58**), aboveground biomass (r = 0.83**) and straw yield (r = 74**) (Figure 4). This indicates that grain yield significantly increases with the increase in number of tiller per plant, panicle height, lodging percent, aboveground biomass, and straw yield. Wakjira [30] indicated that grain yield of tef were significantly and positively correlated with total tiller, panicle length, above ground biomass and straw yield. Grain yield was not significantly correlated with harvest ndex ($r=0.06^{ns}$) and negatively correlated with plant height (r=0.43**).

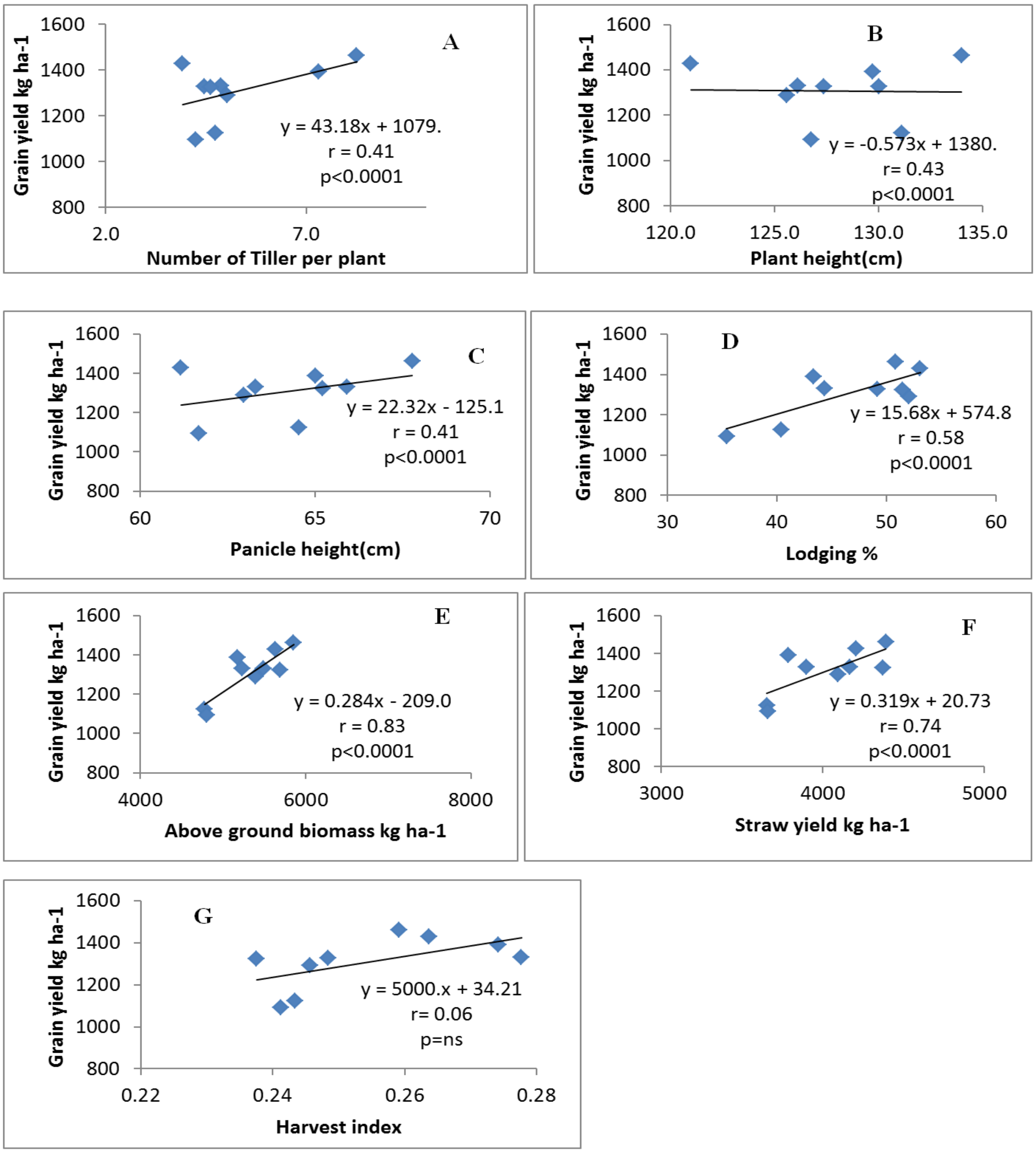



***Figure 5.*** *Correlation analysis of grain yield with number of tiller per plant (A), plant height (B), panicle height (C), lodging percent (D), above ground biomass (E), straw yield (F) and harvest index (G) of tef at Tiroafeta and Buno Bedele.*

Number of tillers per plant of tef was positively and significantly correlated with plant height, panicle height, aboveground biomass and straw yield but negatively correlated with lodging percent and not correlated with harvest index (Table 6). Plant height and panicle height positively and significantly correlated with above ground biomass and straw yield, but negatively correlated with harvest index (Table 6). These results were in line with Wakjira [30].

*Table 6. Pearson Correlation Coefficients among different growth, yield and yield component parameters of tef.*

| | NTP | PH | PAH | LP | AGB | SY | HI |
|---|---|---|---|---|---|---|---|
| NTP | 1 | $0.30^{**}$ | $0.74^{**}$ | $-0.03^{ns}$ | $0.27^{**}$ | $0.22^{**}$ | $0.01^{ns}$ |
| PH | | 1 | $0.33^{**}$ | $0.03^{ns}$ | $0.45^{**}$ | $0.43^{**}$ | $-0.26^{**}$ |
| PAH | | | 1 | $0.16^{*}$ | $0.33^{**}$ | $0.28^{**}$ | $-0.11^{ns}$ |
| LP | | | | 1 | $0.55^{**}$ | $0.58^{**}$ | $-0.48^{**}$ |
| AGB | | | | | 1 | $0.99^{**}$ | $-0.56^{**}$ |
| SY | | | | | | 1 | $-0.67^{**}$ |
| HI | | | | | | | 1 |

* = Significant at P < 0.05; ** = Significant at P < 0.01; ns=non-significant; NTP=Number of tiller per plant; PH=Plant height; PAH=Panicle height; LP=Lodging percent; AGB=Above ground biomass yield; SY=Straw yield and HI= Harvest index.

### *3.10. Economic Analysis*

The official prices of chemical fertilizer (NPS=13.5 birr $kg^{-1}$) and urea (10 birr $kg^{-1}$) were calculated based on stock sale prices of Tiroafeta and Bedele woreda Farmers Cooperative in July, 2013 up to 2016. The sale of grain tef at Tiroafeta and Bedele open market average price was 26.5 $ETBkg^{-1}$. The cost of labor spent on chemical fertilizer application and transport, seed planting (drill, transplanting and broadcasting) and purchase were also used for partial budget analysis. The cost of application and transport of fertilizer was taken to be 15 birr 100 $kg^{-1}$. Grain yield was adjusted by 10% for management difference to reflect the difference between the experimental yield and the yield that farmers could expect from the same treatment [20, 31].

The highest net benefit of 36,738 ETB $ha^{-1}$ was obtained from broadcasting seeds at the rate of 25 kg $ha^{-1}$ with MRR 3351%. Whereas, the lowest net benefit 28,788 ETB $ha^{-1}$ was obtained from the lowest seed rate 5 kg $ha^{-1}$ planted in broadcasting (Table 7). There was a net benefit increase of 27.6% (7,950 $ETBha^{-1}$) by broadcasting seeds at the rate of 25 kg $ha^{-1}$ when compared with that of broadcasting seed at the rate of 5 kg $ha^{-1}$. The Partial budget analysis done by including all treatments showed better net benefit and higher marginal rate of returns for drilling seeds in rows at the rate of 10 kg $ha^{-1}$ and broadcasting seeds at the rate of 25 kg $ha^{-1}$ with values of 4004% and 3351%, respectively (Table 7). Similarly, seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time also had higher marginal rate of return of 633%. The use of the above mentioned top performing tef planting methods could result in 6.33-40 ETB upon investing one Birr for tef production in humid zones of Southwestern part of the country. Therefore, the result of current study in Bedele and Tiro-Afeta woredas suggests that three candidate treatments that is from time of transplanting; a seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time and from seeding method; drill seeds in rows of 20 cm apart at the rate of 10 kg $ha^{-1}$ and broadcast seed at the rate of 25 kg $ha^{-1}$ should be validated for a season in the long run.

*Table 7. Partial budget analysis for transplanting time and sowing methods of tef at Tiroafeta and Bedale during 2013-2016 cropping seasons.*

| Treatment | Grain yield kg $ha^{-1}$ | Adj. Grain yield kg $ha^{-1}$ | Gross returnBirr$ha^{-1}$ | TVC Birr $ha^{-1}$ | Net Benefit Birr $ha^{-1}$ | MRR (%) |
|---|---|---|---|---|---|---|
| Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time | 1462 | 1316 | 38382 | 5050 | 33332 | 633 |
| Seedlings raised in nursery for 20 days ahead of planting then transplanted to plots at sowing time | 1390 | 1251 | 36182 | 4750 | 31432 | - |
| Drill seeds in rows 20 cm at the rate of 5 kg $ha^{-1}$ | 1123 | 1011 | 29708 | 365 | 29343 | 308 |
| Drill seeds in rows 20 cm at the rate of 10 kg $ha^{-1}$ | 1330 | 1197 | 34837 | 490 | 34347 | 4004 |
| Drill seeds in rows 20 cm at the rate of 15 kg $ha^{-1}$ | 1328 | 1195 | 35008 | 615 | 34393 | 37 |
| Drill seeds in rows 20 cm at the rate of 20 kg $ha^{-1}$ | 1289 | 1160 | 34022 | 740 | 33282 | - |
| Drill seeds in rows 20 cm at the rate of 25 kg $ha^{-1}$ | 1325 | 1192 | 35100 | 865 | 34235 | - |
| Broadcast seeds at the rate of 25 kg $ha^{-1}$ | 1428 | 1285 | 37423 | 685 | 36738 | 3351 |
| Broadcast seeds at the rate of 5 kg $ha^{-1}$ | 1092 | 983d | 28973 | 185 | 28788 | - |

*TVC = Total variable cost; MRR= Marginal rate of return; Price of TEF seed = 30 birr $kg^{-1}$; Wage rate =26 Birr man-$day^{-1}$; Retail price of grain = 26.5 birr $kg^{-1}$; Retail price of straw = 80 birr/ 100 kg.

Market prices are ever changing and as such a recalculation of the partial budget using a set of likely future prices (*i.e.*, sensitivity analysis) was essential to identify treatments which may likely remain stable and sustain satisfactory returns for farmers despite price fluctuations. The sensitivity analysis study indicates an increase in the field price of the total variable costs, and a fall in the price of tef grain, which represented a price variation of 15%.

The price changes are realistic under market conditions prevailing at Tiroafeta and Bedele area which were above the minimum acceptable MRR of 100% for the drilling seeds in rows at the rate of 10 kg $ha^{-1}$, broadcasting seeds at the rate of 25 kg $ha^{-1}$, transplanting seedling raised in nursery for 10 days, and drilling seeds in rows at the rate of 5 kg $ha^{-1}$ (Table 8).

***Table 8.*** *Sensitivity analysis of tef production based on a 15% rise in total cost and tef price of gross field benefit fail.*

| Treatment | TVC (ETB ha$^{-1}$) | NB (ETBha$^{-1}$) | Raised cost | Failed benefit | MRR (%) |
|---|---|---|---|---|---|
| Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time | 5808 | 28332 | 345 | 1615 | 468 |
| Seedlings raised in nursery for 20 days ahead of planting then transplanted to plots at sowing time | 5463 | 26717 | - | - | - |
| Drill seeds in rows 20 cm at the rate of 5 kg ha$^{-1}$ | 420 | 24941 | 207 | 471 | 228 |
| Drill seeds in rows 20 cm at the rate of 10 kg ha$^{-1}$ | 564 | 29195 | 144 | 4254 | 2959 |
| Broadcast seeds at the rate of 25 kg ha$^{-1}$ | 788 | 31228 | 224 | 2032 | 906 |
| Broadcast seeds at the rate of 5 kg ha$^{-1}$ | 213 | 24470 | - | - | - |

*TVC = Total cost that varied; NB = Net benefit; ETB = Ethiopian Birr; MRR= Marginal rate of return.

# 4. Conclusion and Recommendation

The planting methods (transplanting at different time, drilling in rows at different seed rates and broadcasting at different seed rates) had a significant effect on growth and yield of tef at Tiroafeta and Bedele. Seedlings raised in nursery for 10 days ahead of planting then transplanted to plots at sowing time, drill seeds in rows of 20 cm apart at the rate of 10 kg ha$^{-1}$ and broadcast seed at rate of 25 kg ha$^{-1}$ gave significantly higher yield than other treatments. Labor intensiveness at the time of planting is the only drawback of transplanting compared to direct seeding and planter is must. Based on the partial budget analysis the higher net benefit and higher marginal rate of return were obtained from drill seeds in rows of 20 cm apart at the rate of 10 kg ha$^{-1}$ and broadcast seed at rate of 25 kg ha$^{-1}$ with values of 4004% and 3351%, respectively. This is, therefore, drill seeds in rows of 20 cm apart at the rate of 10 kg ha$^{-1}$ and broadcast seed at rate of 25 kg ha$^{-1}$ can be used to high and economic yield of tef in the study area.

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