# Effects of Sowing Methods, Seed Rates and Sowing Depths on Growth Performance and Grain Yield of Tef [*Eragrostis tef* (Zucc.) Trotter]

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## Abstract

Three field experiments were carried out on black soil (Vertisols) at Debre Zeit Agricultural Research Center during the main season between 2011 and 2013 to determine appropriate sowing/planting methods, seed rates, inter- and intra-row spacings, and planting depth for tef. Each experiment was laid out in a randomized complete block design with three replications. Data were taken on days to panicle emergence and to maturity, plant height, panicle length, lodging index, shoot biomass, and grain yield. Combined analyses of variance over years showed that sowing methods had no significant effect on any of the traits assessed, while sowing methods and seed rates interaction effects were significant for all the traits evaluated. Irrespective of sowing methods significantly higher grain yields were recorded with higher seeding rates (10-25 kg/ha). Among the spacing treatments, sowing with 10 cm row spacing showed the highest mean grain (2621 kg/ha) and shoot biomass (21861 kg/ha) yield. Hill planting irrespective of the row spacing gave the lowest grain and shoot biomass yield, while transplanting, gave intermediate grain and shoot biomass yield comparable to those of row sowing. In the third experiment that combined row spacing and sowing depth, the highest grain yield (2404 kg/ha) was obtained from 20 cm row spacing by 3 cm planting depth followed by 20 cm row spacing by 5 cm planting depth (2292 kg/ha). Overall, based on the results of this study, seed rates of 10-15 kg/ha for both broadcasting and row spacing, and row spacing of 20 cm and sowing depth of 3 cm would be recommended for tef production on black soils at Debre Zeit and other similar areas.

**Key Words:** Sowing methods, seed rates, hill planting, row sowing, transplanting, sowing depth

## Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is one of the most important cereal crops in Ethiopia. It is cultivation on about 3.02 million hectares with corresponding grain harvests of 4.42 million tons. Tef accounts for over 30% of the total annual area (9.85 million ha) and over 20% of the yearly gross grain production (21.56 million tons) of all cereals grown in the country (CSA, 2014). The long continued extensive cultivation of tef by the Ethiopian farmers is accentuated by a number of its relative merits over the other cereals with respect to both husbandry and utilization (Seyfu, 1993; Hailu *et al.*, 2001; Kebebew *et al.*, 2011; 2012; 2013). This includes, among others, broad adaptation from low lands up to over 3000 meters above sea level, resilience to marginal conditions including high (waterlogging) and low moisture stresses, good nutritional value and preference as a staple food by many Ethiopians. Furthermore, tef has invaluable use as its straw primarily used as cattle feed, and cash crop for the farmers due to the high market prices of both the grains and straw.

In spite of the supreme significance of tef in the Ethiopian agriculture, its productivity has been relatively low with the national average yield of 1.5 tons $ha^{-1}$ (CSA, 2014). This, among others, has been due to the widespread use by the tef growing smallholder farmers of unimproved varieties coupled with traditional management practices, and susceptibility of the crop to lodging.

In traditional production system, farmers' often broadcast tef seeds using high seed rates on the surface of the soil leaving the seeds uncovered or sometimes very lightly covered. This practice normally results in high number of plants per unit area, thereby, resulting in plant crowding and competition for resources among the plants. This, in turn, results in plants with weaker stems that easily succumb to severe lodging.

Lodging is the major bottleneck in tef production due both its direct and indirect effects. Its direct harmful manifestations include reductions of the yields by up to 25% and quality in terms of color and germination capacity of the grains (Seyfu, 1983; 1987; 1993); and posing difficulties in both manual and mechanical harvesting operations; and deterioration in the quantity as well as quality of the straw residue. Furthermore, the harmful indirect effects of lodging include restrictions to the use of growth and yield promoting high input husbandry conditions such as nitrogen fertilizers.

The results of previous agronomic studies pertaining to the present studies have comprehensively been reviewed by Fufa *et al*. (2001). Generally, the former studies on seeding rates and planting methods carried out at Debre Zeit, Akaki and Chefe Donsa revealed no substantial effects of sowing methods (broadcast *versus* drilling in rows) and seed rates (15-55 kg/ha) on grain and biomass yield of tef (DZARC, 1987; 1988; 1989; Seyfu, 1993). Likewise, seeding rate trials with rates varying from 10-40 kg/ha in various locations including Jima (Tesfa and Gebremariam, 1986), Kobbo (IAR, 1988; Abuhay and Hailemariam, 1986), Sinana and Bako (IAR, 1974) generally showed an increasing trend in grain yield with increasing seed rates while in most cases the differences were not statistically significant. On the other hand, studies with the use of fillers (equal-sized sand particles) in proportions of 0:1, 2:1 and 4:1 sand to seed ratios in combinations with different seed rates (15, 25, 40 and 55 kg/ha) similarly showed no significant effects of fillers, seed rates and their interactions on the grain yield of tef (DZARC, 1987; 1988, 1989; Mulu *et al*., 1994). Based on the findings of the afore-mentioned various studies and considering the difficulties in row sowing and manual broadcasting of small amounts of seeds, a general recommendation of 25-30 kg/ha seed rate was made for tef sowing (Seyfu, 1987; 1993).

Recently, row sowing has been reported to reduce lodging and increase productivity (Tareke *et al*., 2013; Vandercasteleen *et al*., 2014). Although not from a well designed replicated trial, Berhe *et al*. (2013) from a field observation experiment on black soil at Debre Zeit reported a three-fold increase in both grain and straw yield by reducing seed rate to 2.5 kg/ha from the earlier recommendation of 25-30 kg/ha, and transplanting seedlings in a row, and applying appropriate types of fertilizer instead of the commonly used DAP and urea. On the other hand, Vandercasteleen *et al*. (2014) stated that by implementing row planting farmers reported yield increases of only 2-12% on the average.

In view of the recent developments, therefore, the present agronomic field experiments were carried out in order to assess the effects on growth and yield of tef and thereby determine (1) appropriate sowing method and seed rate; (2) optimum inter-and intra-row spacing, and depth for drill planting of tef seeds; and (3) optimum inter-and intra-row spacing for transplanting tef seedlings.

# Materials and Methods

Three agronomic experiments were carried out on black soils at Debre Zeit Agricultural Research Center during the 2011 – 2013 main cropping seasons. The experiments include factorial combinations of sowing method by seed rate, planting method by spacing, and planting depth by row spacing.

## Sowing method and seed rate

Sowing method by seed rate experiment was conducted on black soil (Verisols) at Debre Zeit Agricultural Research Center during the 2011-2013 main seasons using seeds of a popular tef variety, Quncho. Twelve factorial treatment combinations of two sowing methods (broadcasting and drilling in rows spaced at 20 cm) and six seed rates (2.5, 5, 10, 15, 20 and 25 kg/ha) were evaluated in tri-plicated randomized complete blocks with plot sizes of 3 m x 3 m (= 9 $m^2$).

Data were recorded on days to panicle emergence and maturity, plant height, panicle length, lodging index, shoot biomass, and grain yield. The data were subjected to combined analyses of variance (ANOVA) after testing for homogeneity of error variances, and other data exploration tools.

## Planting method and spacing

Ten treatment combinations of different sowing methods (broadcasting and row sowing) with different row spacings, hill planting with different row and plant spacing, and transplanting with different row and plant spacing were laid out in randomized complete blocks with three replications of 3m x 3m (9$m^2$) plots on black soil at Debre Zeit Agricultural Research Center during the 2011-2013 main seasons. The planting material used was the most popular tef variety called Quncho, at seed rate of 5 kg/ha both for broadcasting and row sowing and 3 seeds/hill for hill planting.

Data were recorded on days to panicle emergence, days to maturity, plant height, panicle length, lodging index, tiller number, shoot biomass, and grain yield. The data were subjected to combined analyses of variance (ANOVA) over years after confirmation of homogeneity of error variance.

### Planting depth and row spacing

Twelve treatment combinations of different sowing depths (0, 3 and 5 cm) and row spacing (10, 15, 20 and 25 cm) were laid out in a randomized complete block design with three replications on black soil using 9 $m^2$ plot size at Debre Zeit Research Center during the 2011and 2012 main cropping seasons. The tef variety Quncho was used at uniform seed rate of 5 kg/ha.

Observations were made on days to maturity, plant height, panicle length, lodging index, shoot biomass, and grain yield. The data were subjected to combined analyses of variance (ANOVA) over years after confirmation of homogeneity of error variance.

## Results and Discussion

### Sowing method by seed rate

The combined analysis of variance over years revealed that main effects of seed rate, and the interaction effects of seed rates by sowing methods were significant for all the six traits assessed, such as days to maturity, panicle length, plant height, lodging index, shoot biomass and grain yield (Table 1). But the main effects of sowing methods (broadcasting *versus* row sowing) were significant only for days to maturity. On the other hand, days to panicle emergence was not significantly affected by sowing methods, seed rates and the interaction of these two factors.

Combined analyses of variance over two years revealed significant differences among seed rates for grain and shoot biomass yield (Table 1). For both shoot biomass and grain yields, lower seed rates showed significantly lower mean values than the higher seed rates. As such the least mean grain yield (1556 kg/ha) and shoot biomass yield (8058 kg/ha) were observed for the lowest seed rate of 2.5 kg/ha. One of the higher seed rates (20 kg/ha) showed a maximum grain yield of 2545 kg/ha, which is about 64% and 47% grain yield advantages over the two lower seed rates of 2.5 and 5 kg/ha, respectively. The highest mean shoot biomass yield of 17051 kg/ha was noted for the highest seed rate of 25 kg/ha, and this showed significantly higher yield advantages of about 112%, 83% and 23% over the three lower seed rates of 2.5, 5 and 10 kg/ha, respectively.

Considering the interaction effects of sowing methods and seed rates, significantly higher mean grain yield for both broadcasting and row sowing were noted for the higher seed rates of 10 kg/ha or above as compared to the lower seed rates of 2.5 and 5 kg/ha. A seed rate of 20 kg/ha generally showed the highest grain yield under both broadcast and row sowing.

In line with the present findings, significant tef grain yield differences due to seed rates were also reported in previous studies with the use of fillers on both light and black soils at Debre Zeit (DZARC, 1987). In these studies higher seed rates appeared beneficial than seed rate as low as 15 kg/ha. In contrast, no substantial differences in mean grain yields of tef was observed using seed rates ranging from 10-55 kg/ha at Sinana and Bako (IAR, 1974), at Kobbo (Abuhay and Hailemariam, 1986; IAR, 1988), at Jima (Tesfa and Gebremariam, 1986), and at Debre Zeit (DZARC, 1988; 1989).

On the other hand, when averaged over all seed rates, there were no significant mean grain yield differences between the two sowing methods, broadcasting (2173 kg/ha) *versus* drilling in rows (2177 kg/ha) (Table 1). The effects of sowing methods on grain yield were not consistent across seasons (Figure 1). Across all seed rates, grain yield was highly influenced by sowing methods only during the first season. This implies that seed rate alone could not necessarily influence grain yield per unit area. Contrary to first year's grain yield response, during the second season sowing methods had no effect on grain yield across all the seed rates studied.

The effects of seed rates and sowing methods on tef grain yield combined over the two years are presented in Figure 2. The overall effect of row planting was found to be higher than broadcasting across all seed rate levels. But the row drill planting response was highly variable between the two seasons. The crop responded with lower but stable grain yield performance to broadcasting as opposed to row planting over the two seasons.

Similar to the present results, earlier studies with tef showed no significant yield differences between broadcasting and row sowing (DZARC, 1987; 1988; 1989; Seyfu, 1993). By comparison, estimates from recent quantitative and qualitative surveys made in various tef growing parts of Ethiopia indicated that farmers harvested addition tef grain yield of 2-12% due to row sowing as opposed to broadcasting (Vandercasteleen *et al*., 2014). From an observation trial conducted on black soil at Debre Zeit Agricultural Research Center, Berhe *et al*. (2013) reported a three-fold yield increase due to combined use of reduced seed rate, transplanting and use of appropriate fertilizer types.

## Planting method and spacing

Of all the seven traits evaluated (i.e, days to panicle emergence and maturity, plant height, panicle length, tiller number, lodging index, shoot biomass and grain yield), the combined analyses of variance over two years showed significant differences among the planting methods by spacing combinations only for grain yield, shoot biomas and lodging index. Sowing with 10 cm row spacing showed the highest mean grain (2621 kg/ha) and shoot biomass (21861 kg/ha) yield. Hill planting irrespective of the row spacing gave the lowest grain and shoot biomass yield, while transplanting regardless of the row spacing gave intermediate grain and shoot biomass yields that were higher than those of hill planting and slightly lower but statistically comparable to those of row sowing.

Transplanting at 20 cm between rows with 15 cm between plants showed the lowest (46) mean lodging index value (Table 2) followed by transplanting at 20 cm between rows and 10 cm between plants (49) and transplanting at equal spacings of 20 cm between rows and plants within rows (56). Hill planting of tef seeds (3 plants/hill), regardless of the spacings between rows and hills, did not result in reduced lodging incidence as expected.

In the present experiment, row sowing and broadcasting showed statistically comparable grain and shoot biomass yield, but hill planting was the least yielding method. Similarly, previous studies at Debre Zeit Agricultural Research Center showed no significant grain yield differences between broadcasting and row sowing (DZARC, 1987; 1988; 1989; Seyfu, 1993). On the other hand, surveys in different tef growing areas in 2013 main season showed that famers reported average yield increments of 2-12% due to row sowing along with reduced seed rates (Vandercasteleen *et al.*, 2014).

Table 1. Mean agronomic and grain yield performance of tef as affected by sowing methods and seed rates on black soil at Debre Zeit during 2011-13.

| Treatment combination | | Days to maturity | Panicle length (cm) | Pant height (cm) | Lodging index | Shoot biomass (kg/ha) | Grain yield (kg/ha) |
|---|---|---|---|---|---|---|---|
| Sowing methods | Seed rates (kg/ha) | | | | | | |
| Broadcasting | 2.5 | 105.0b | 46.8abc | 109.0bc | 68.8abc | 8861.0ef | 1709.6b |
| | 5 | 106.0a | 45.8bc | 105.9c | 56.0c | 8079.0f | 1701.5b |
| | 10 | 106.0a | 48.6ab | 116.9 | 64.3cd | 13625.0d | 2398.0a |
| | 15 | 106.0a | 49.1a | 115.3 | 71.2ab | 14694.0bcd | 2397.2a |
| | 20 | 105.0b | 48.1abc | 115.2 | 73.8ab | 16824.0ab | 2467.4a |
| | 25 | 106.0a | 49.3a | 112.1abc | 73.8ab | 17375.0a | 2364.8a |
| Row sowing | 2.5 | 106.0a | 45.2c | 105.9c | 68.7abc | 7255.0f | 1403.2b |
| | 5 | 105.0b | 49.0a | 113.5ab | 64.5bcd | 10542.0e | 1754.5b |
| | 10 | 106.0a | 49.4a | 115.6ab | 69.8abc | 14069.0cd | 2343.9a |
| | 15 | 105.0b | 48.6ab | 116.6a | 76.0a | 16111.0abc | 2411.5a |
| | 20 | 105.0b | 49.0a | 118.9a | 75.3ab | 16810.0ab | 2622.4a |
| | 25 | 106.0a | 49.1a | 115.2ab | 70.8abc | 16727.0ab | 2528.3a |
| LSD (0.05) | | 1.7 | 3.1 | 7.2 | 11.4 | 2329.1 | 502.5 |
| **Means of sowing methods (over all seed rates)** | | | | | | | |
| Broadcasting | | 106.0 a | 48.0 | 112.4 | 68.0 | 13585.6 | 2173.1 |
| Row sowing | | 105.0 b | 48.4 | 114.3 | 70.9 | 13243.1 | 2177.3 |
| LSD (0.05) | | 0.7 | NS | NS | NS | NS | NS |
| **Means of seed rates (over both sowing methods)** | | | | | | | |
| 2.5 | | 105.0b | 46.0b | 107.5c | 68.8a | 8057.9d | 1556.4b |
| 5 | | 105.0b | 47.4ab | 109.7bc | 60.3b | 9310.2d | 1728.0b |
| 10 | | 106.0a | 49.0a | 116.2a | 67.1ab | 13847.2c | 2370.9a |
| 15 | | 106.0a | 49.0a | 116.0a | 73.6a | 15402.8bc | 2404.4a |
| 20 | | 105.0b | 48.6ab | 117.0a | 74.6a | 16817.1ab | 2544.9a |
| 25 | | 106.0a | 49.2a | 113.6ab | 72.3a | 17050.9a | 2446.6a |
| LSD (0.05) | | 1.2 | 2.2 | 5.1 | 8.1 | 1646.9 | 355.3 |
| Overall mean | | 106.0 | 48.2 | 113.3 | 69.4 | 13414.4 | 2175.2 |
| Overall SEM (±) | | 0.5 | 0.4 | 0.9 | 1.3 | 727.8 | 79.9 |
| CV (%) | | 1.4 | 5.5 | 5.5 | 14.1 | 14.9 | 19.9 |

Means within the same column and the same treatment category followed by different letters are significantly different at P≤0.05.

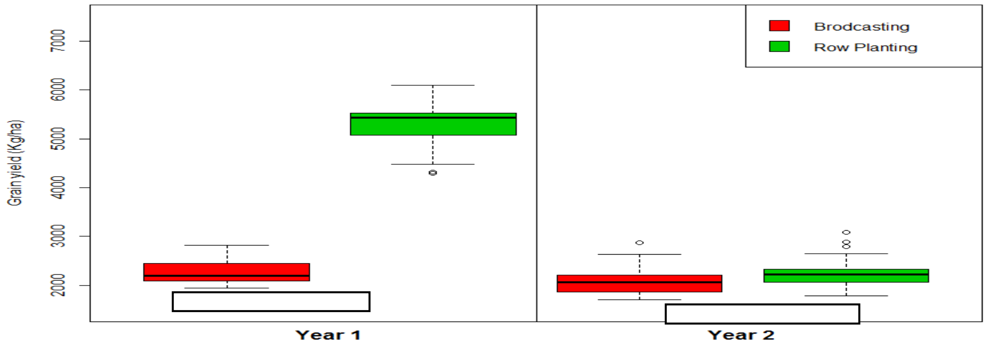


Figure 1. Box plot representation of grain yield as affected by different planting methods (broadcasting vs. sowing in rows).

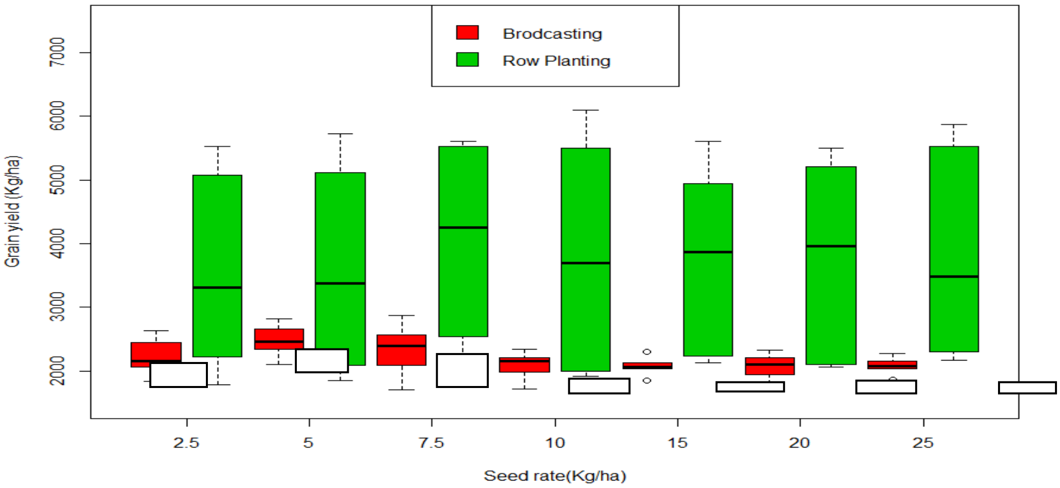


Figure 2. Box plot representation of grain yield as affected by different planting methods (broadcasting vs. sowing in rows) and seed rates.

In the present experiment, row sowing and broadcasting showed statistically comparable grain and shoot biomass yield, but hill planting was the least yielding method. Similarly, previous studies at Debre Zeit Agricultural Research Center showed no significant grain yield differences between broadcasting and row sowing (DZARC, 1987; 1988; 1989; Seyfu, 1993). On the other hand, surveys in different tef growing areas in 2013 main season showed that famers reported average yield increments of 2-12% due to row sowing along with reduced seed rates (Vandercasteleen *et al*., 2014).

Generally, our findings did not show any substantial advantages of transplanting over direct sowing on grain and shoot biomass productivity of tef as was suggested by Tareke *et al.* (2013). On the other hand, hill planting was tested with the hope for future developments such as seed pellet technologies which allow the use of machinery for drill planting of tef.

## Planting depth and row spacing

Among the traits evaluated in this experiment, significant effects of planting depth and row spacing were noted only for lodging index, shoot biomass, and grain yield. Considering these traits, the combined analyses of variance over two years (2011 and 2012) showed no significant main effects of planting depth on all of these three traits (Table 3).

Table 2. Mean grain yield, shoot biomass and lodging index of tef as affected by planting method treatments on black soil at Debre Zeit during 2011 and 2012.

| Treatment | Lodging index | Shoot Biomass (kg/ha) | Grain yield (kg/ha) |
|---|---|---|---|
| Broadcasting (5 kg/ha seed rate) | 64.8abc | 16903.0bcd | 2489.8a |
| Row sowing (5 kg/ha seed rate ) with 20 cm row spacing) | 72.3a | 19653.0abc | 2440.6a |
| Row sowing (5 kg/ha seed rate) with 15 cm row spacing) | 67.5ab | 17273.0bc | 2320.0a |
| Row sowing (5 kg/ha seed rate) with 10 cm row spacing) | 71.3a | 21861.0a | 2621.3a |
| Hill planting (3 seeds/hill) with 20 cm inter- and 20 cm intra-row spacing | 64.0abc | 8495.0g | 1505.7bc |
| Hill planting (3 seeds/hill) with 20 cm inter- and 15 cm intra-row spacing) | 59.5bc | 6440.0g | 1344.6bc |
| Hill planting (3 seeds/hill) with 20 cm inter- and 10 cm intra-row spacing | 65.0abc | 9870.0fg | 1613.3b |
| Transplanting (3 seedlings/hill) with 20 cm inter- and 10 cm intra-row spacing | 49.0de | 15468.0cde | 2208.9a |
| Transplanting (3 seedlings/hill) with 20 cm inter- and 15 cm intra-row spacing | 46.3e | 13532.0de | 2236.9a |
| Transplanting (3 seedlings/hill) with 20 cm inter- and 20 cm intra-row spacing | 56.3cd | 12722.0ef | 2181.7a |
| Mean | 61.6 | 14221.8 | 2096.3 |
| LSD (P≤0.05) | 9.7 | 3579.6 | 489.3 |
| SEM (±) | 2.0 | 1169.3 | 84.4 |
| CV (%) | 13.5 | 21.5 | 20.0 |

Means within the same column followed by the same letter are not significantly different as judged by LSD at P≤0.05.

On the other hand, the main effects of row spacing were significant for lodging index, shoot biomass, and grain yield. The highest mean grain yield (2275 kg/ha) was recorded for 20 cm row spacing followed by 10 cm row spacing (2135 kg/ha) and 15 cm row spacing (1900 kg/ha), whereas the lowest mean grain yield (1605 kg/ha) was recorded for the widest row spacing of 25 cm. In terms of shoot biomass yield, the highest value (13100 kg/ha) was depicted by the narrowest row spacing of 10 cm while the lowest mean shoot biomass yield (11242 kg/ha) was obtained with the widely spaced rows (25 cm). The two intermediate row spacings of 15 and 20 cm had produced similar yield, but significantly different from the narrowest spacing. On the other hand, lodging index did not show clear trends with increasing row spacing as the only statistically significant difference was noted between the lowest mean lodging index (67.3) for 20 cm row spacing and the highest lodging index mean (72.1) for the narrowest row spacing of 10 cm.

Table 3. Mean lodging index, and shoot biomass and grain yield of tef as affected by row spacing and planting depth on black soil at Debre Zeit during the 2011-13 main seasons.

| Treatments | | Lodging index | Shoot biomass (kg/ha) | Grain yield (kg/ha) |
|---|---|---|---|---|
| Row spacing (cm) | Sowing depth (cm) | | | |
| | 0 | 73.3abc | 14620.4ab | 2277.0abc |
| 10 | 3 | 68.2bcd | 15652.8a | 1979.3bcde |
| | 5 | 74.7ab | 14092.6abc | 2149.6abcd |
| | 0 | 66.8bcd | 13166.7bcd | 2011.3bcde |
| 15 | 3 | 69.3bcd | 12736.1bcd | 1896.3cde |
| | 5 | 68.0bcd | 13949.1abc | 1811.7de |
| | 0 | 64.3d | 12393.5bcd | 2130.4abcd |
| 20 | 3 | 69.8bcd | 13740.7abc | 2404.3a |
| | 5 | 67.8bcd | 12685.2bcd | 2291.9ab |
| | 0 | 80.2a | 12217.6cde | 1866.7de |
| 25 | 3 | 65.8cd | 11416.7de | 1712.6ef |
| | 5 | 69.8bcd | 10092.6e | 1416.3f |
| LSD (0.05) | | 8.09 | 2233.30 | 386.98 |
| Means of sowing depth (Over all row-spacings) | | | | |
| | 0 | 71.2a | 13099.5a | 2071.3a |
| | 3 | 68.3a | 13386.6a | 1998.1a |
| | 5 | 70.1a | 12704.9a | 1917.4a |
| LSD ( 0.05) | | NS | NS | NS |
| Means of row spacings (Over all sowing depth treatments) | | | | |
| 10 | | 72.1a | 14788.6a | 2135.3a |
| 15 | | 68.1ab | 13284.0b | 1906.4b |
| 20 | | 67.3b | 12939.8b | 2275.5a |
| 25 | | 71.9ab | 11242.3c | 1665.2c |
| LSD (0.05) | | 4.70 | 1289.40 | 223.4 |
| Overall SEM (±) | | 1.03 | 907.83 | 67.18 |
| Overall mean | | 69.90 | 13063.66 | 1995.6 |
| CV (%) | | 9.97 | 14.71 | 16.69 |

Means within the same column and the same treatment category followed by a similar letter are not significantly different as judged by LSD at P≤0.05.

Considering the treatment combinations at large, there were significant differences in all the traits including lodging index, as well as shoot biomass and grain yield (Table 3). The highest grain yield (2404 kg/ha) was obtained from the treatment combination of row sowing at 20 cm spacing by 3 cm planting depth followed by similar 20 cm row spacing by 5 cm planting depth (2292 kg/ha) (Table 3). With regard to shoot biomass, the highest mean yield (15652 kg/ha) was obtained from the treatment combinations of 10 cm row spacing by 3 cm sowing depth followed by 10 cm row spacing by on-surface sowing (0 cm depth) (14620 kg/ha). This indicates that as spacing between rows decreases, the number of plants per unit area increases which results in high biomass yield. The lowest mean grain (1416 kg/ha) and biomass (10092 kg/ha) yields were obtained from the treatment combination of 25 cm row spacing by 5 cm planting depth.

In general, the results indicated that 20 cm row spacing appears to be optimum for better shoot biomass and grain yields production. It also allows carrying out agronomic management practices such as weeding and fertilizer application and avoids high resource competition. Sowing tef seeds in rows also saves planting seed stocks. Regarding sowing depth, surface sowing (0 cm) and 3 cm appear acceptable depth because going beyond 3 cm depth could cause poor germination due to failure of seedlings to emerge out from deep soil. Hence, to avoid risk of poor germination, 0-3 cm sowing depth would be appropriate and recommended.

The normal row spacing of small grain cereals (wheat, barley, oats, rye) in humid temperate areas such as Scandinavians is around 12 cm, and the spacing in such areas has sometimes been 15-20 cm or more, while in many arid areas the row spacing is traditionally larger (Hakansson, 2003). In other instances, the effect of row spacing (up to 50 cm) varied depending upon the potential yield, and increasing row spacing is not always beneficial to yield (GRDC, 2011a; b).

In a field experiment with red spring wheat in central Montana, USA, greater biomass accumulation occurred with 15 cm row spacing as compared to 30 cm row spacing while grain yield at the two trial seasons (2004 and 2005) was 410-412 kg/ha greater at 15 cm than at 30 cm row spacing (Chen *et al.*, 2008).

Generally, seeds can more precisely be sown into the soil by maintaining a planting depth of about 2-3 times the size of the seed (http://en.wikipedia.org/wiki/sowing). In comparison to this general fact, the sowing depth range for the ovoid or oblong to ellipsoidal shaped tef caryopsis which is 0.9 mm long and 0.7-1.0 mm in diameter (Tadesse, 1975), planting depth would be only 2.7-5.1 mm. But in the present study 3 cm depth was found optimum. On the other hand, the ideal seeding depth for small grains is 1-1.5 inches (i.e. about 2.54 - 3.81 cm) depending on soil type and moisture (http://msucar.com/pubs/publications). While "small grains" in the latter case refer to cereals such as wheat, barley, rice, and oats which have got bigger kernels than tef.

# Conclusion

The results of the seed rate by sowing method experiment generally did not meet the expectations that row planting would remarkably increase grain yield. However, row sowing has a lot of other agronomic benefits over broadcasting in terms of ease of subsequent cultural operations including weeding and harvesting, and with respect to enabling efficient use of fertilizers. The latter is because the fertilizers can be applied as row-side bands such that nutrients would be available to plants better than that of the scattering of fertilizers all over the field as is the case of broadcasting. Generally, for tef, it is advisable to go for sowing in rows particularly if farmers could use of suitable sowing implements. Considering the lack of tef row seeder at the moment, it would be advisable to use 10-15 kg/ha seed rate for both row and broadcast sowing. This gives equivalent or higher yield as compared to the use of higher seed rates and saves at least 10-15 kg/ha of planting seeds as compared to the previously recommended seed rate of 25-30 kg/ha. In general, transplanting method did not result in increased productivity of tef over direct row sowing in terms of both grain and straw yield. The present results indicated that direct row sowing gave slightly higher grain yield than seedling transplanting method. Therefore, direct sowing is recommended in view of its low labor requirement for tef production. The use of 20 cm row spacing and planting depth of 3 cm in tef husbandry would be more feasible if smallholder tef farmers would get better access to user-friendly farm implements enabling them to implement these recommendations at farm level.

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