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Evaluation of Seed Rates and Sowing Methods on Growth, Yield and Yield Attributes of Tef [*Eragrostis tef* (Zucc.) Trotter] in Ada District, East Shewa, Ethiopia

[1]Abraham Reda, [2]Nigussie Dechassa and [3]Kebebew Assefa

[1]Crop and Horticulture, Ethiopian Biodiversity Institute, Mekelle Centre, Ethiopia
[2]School of Plant Sciences, Harmaya University, Ethiopia
[3]National Tef Research Coordinator, Debre Zeit Agricultural Research Center, Ethiopia

Abstract: Tef is a major staple cereal crop in Ethiopia. However, its productivity is limited, amongst others, by the use of improper sowing methods and inappropriate seed rates. A field experiment was conducted at Debre Zeit Agricultural Research Centre, East Shewa Zone during the 2012 main cropping season under rain-fed condition, to assess the effect of seed rates and sowing methods on growth, yield and yield attributes of tef. Factorial combinations of two sowing methods (Row and broadcast) and six seeding rates (2.5, 5, 10, 15, 20 and 25 kg ha^{-1}) were laid out in a randomized complete block design (RCBD) with three replications. Seed rate significantly affected days to panicle emergence, days to physiological maturity, main panicle weight, main panicle seed weight and thousand seed weight. Accordingly, the maximum values of these parameters were obtained at the seed rate of 2.5 kg ha^{-1}. Moreover, significant main effects of both seed rate and sowing method were observed on the number of total tillers, productive tillers, plant height and grain yield. Row planting method and seed rate of 2.5 kg ha^{-1}had produced the maximum number of total and productive tillers with concurrent decrease in plant height and grain yield as compared to the other treatments. Higher grain yield of 2702 kg ha^{-1} was obtained at seeding rate of 25 kg ha^{-1} followed by 15 and 20 kg ha^{-1} which had produced grain yield of 2453 and 2371 kg ha^{-1}, respectively. There were significant interaction effects of sowing methods and seed rates on shoot biomass yield, straw yield, lodging percentage, culm length and harvest index. The highest seed rate of (25 kg ha^{-1}) with both sowing methods produced higher shoot biomass yield, straw yield and lodging percentage. However, combining the highest seeding rate with the broadcasting method resulted in lower harvest index. Lodging index was consistently increased with increasing seed rate under row planting. Hence, considering the growth and yield obtained from the current study by using 25 kg ha^{-1} seed rate together with row planting can be suggested for higher tef production in the study area.

Key words: Tef · Row Sowing · Broadcasting · Seed Rate · Yield and Yield Attributes

INTRODUCTION

Tef [*Eragrostis tef* (Zucc.) Trotter] is an indigenous C_4, self-pollinated, chasmogamous annual warm season grass that is used throughout Ethiopia as grain crop for human consumption and as forage for livestock [1]. Taxonomically, it belongs to the grass family, Poaceae, sub-family Chloridoideae (Eragrostoideae), tribe Eragrostidae, sub-tribe Eragrostae and genus *Eragrostis* [2]. It has a fibrous root system with mostly erect stems, although some cultivars are bending or elbowing types [3]. In cultivation as a cereal, tef is the only species in the genus *Eragrostis* together with finger millet (*Eleusine crocana* L.) and they constitute the sole two species in the sub-family Chloridoideae cultivated for human consumption of the grains [3]. Tef is an endemic cereal crop of Ethiopia and its major diversity is found only in Ethiopia. According to Vavilov [4] Ethiopia is the geographical centre of origin and diversity. The word tef is said to have probably originated from the Amharic word "*tefa*" which means lost because of its small grain size which is difficult to find once it is dropped while other more plausible sources state that it was derived from Arabic word tahf, a name given to a similar wild plant used by Seimites of south Arabia during the time of food insecurity [5].

Corresponding Author: Abreham Reda, Crop and Horticulture, Ethiopian Biodiversity Institute, Mekelle Centre, Ethiopia.

Tef performs well above any other major crops grown under unfavourable circumstances such as low moisture conditions and is often considered as a rescue crop in seasons when early planted crops such as maize fail due to moisture stress [6]. Moreover, its ability to grow in waterlogged areas tolerating anaerobic conditions is better than that of many other cereals, including maize, wheat and sorghum, making it a preferred cereal by farmers [7]. According to CSA [8] tef is one of the most important cereals being grown in Ethiopia and accounts for about 22.6% of the total area and 16% of the gross grain production of the major cereals cultivated in Ethiopia. The area devoted to tef cultivation is on the increase owing to the versatile merits of tef to Ethiopian farmers. Firstly, both the grain and straw fetch relatively higher prices in the market in comparison to those of other major cereal crops [9]. The fact that tef has become an export item will also increase farmers cash income in the future. Secondly, tef is an excellently adapted crop to the diverse environments in the country [10, 11]. Tef production has been increasing from year to year and so does the demand for it as staple grain in both rural and urban areas of Ethiopia [12]. The production trend of tef has shown an increment by 16.76%, 11.69%, 10.96% and 7.97% over the 2007/08, 2008/09, 2009/10 and 2010/11 respectively [8]. Despite the aforementioned importance and coverage of large area, its productivity is very low when it is compared with cereal crops like maize and wheat. The national average yield is 1.28 t ha^{-1} for tef that is 57% below the national average maize yield and 37% below the national average wheat yields [8].

This low yield and productivity is mainly due to the traditional farming system which is not supported by improved technologies such as proper sowing method and optimum seed rate [13].The small size of tef seed poses problems during sowing and indirectly also in the weeding and threshing operations. At sowing, the very small seed size makes it difficult to control population density and even distribution. Farmers usually use higher seeding rates than those given by research recommendations, which may be due to their unclean seed with lower germination rate and apparently also to minimize weed infestation [2]. Plant density is one of the major factors determining the ability of the crop to capture resources; it is of particular important that it is being under a fairly close control by the farmers in most tef-producing systems. There has been an interest in defining the relationships between seed rate and sowing method on crop yield in order to establish optimum populations to reach the attainable yields. As a result, the effects of seed rate and sowing method on tef plant characters and crop productivity has received greater attention in this study. Aiming at increasing the growers' productivity through strategic manipulations of sowing method and seed rate in Ada District of East Shewa is of paramount importance. Therefore, the study was initiated with the following specific objectives:

- To assess the effect of seed rates and sowing methods on growth, yield and yield attributes of tef

MATERIALS AND METHODS

Description of the Study Area: The field experiment was carried out on a vertisol at Debre Ziet Agricultural Research Centre (DZARC) in Ada district of East Shewa, Ethiopia under rain-fed condition during the 2012 main cropping season from June to November. DZARC is located at $08^0 44^{''}$N latitude and 38° $58^{''}$E longitude (47 km South-East of Addis Ababa) and at an altitude of 1900 metres above sea level. It receives annual rainfall of 1100 mm [14] and has average annual minimum and maximum temperatures of 8.9 and 28.3ºC, respectively. At Debre Zeit, the rain for the main growing season usually commences after mid-June and terminates in the last week of September. The total rainfall received between these months during the 2012 cropping season was 628.3 mm, but the long-term average rainfall is 1100 mm per annum. The soil of DZARC is very fine clay, Montmorilloitic, Isothermic and classified as Typic Pellusterts [15]. The area is nationally known for the production of the best quality tef, which dominates the agricultural production system of the area [16].

Crops including, tef, wheat, barley, maize, sorghum, faba bean, field pea, lentil, safflower, niger seed, linseed, sesame and Ethiopian mustard are grown predominantly during the wet season whereas chickpea is produced on residual soil moisture during the relatively dry season beginning from late August [16].

Weather Conditions: Weather data (Minimum and maximum air temperature, rainfall, humidity and wind speed) of Debre Zeit during the experimental cropping season are presented in Table 1. The minimum and maximum temperatures and total monthly rainfall at Debre Zeit Agricultural Research Centre for the months of June to October were about 11.68°C, 26.04°C and 628.3 mm, respectively, while the mean relative humidity was 62%.

Experimental Material

Plant Material: Tef variety Quncho (DZ-Cr-387 RIL355), which was developed and released by Debre Zeit Agricultural Research Centre in 2006 [17] was used as a

Table 1: Mean Days to seedling emergence, panicle emergence and physiological maturity of tef as affected by sowing method and variable seed rates.

	Days to		
Treatment	Emergence	Panicle emergence	Maturity
Seed rates (kg ha^{-1}) (Means over both sowing methods)			
2.5	4.67	43.50a	109.30a
5	4.50	43.00ab	108.00ab
10	4.67	42.67abc	104.20bc
15	4.33	42.00bcd	101.80cd
20	4.17	41.67cd	98.20d
25	4.33	41.00d	98.20d
Mean	4.44	42.31	103.28
LSD (0.05)	NS	1.19	4.48
Sowing methods (Means over all seed rates)			
Row sowing	4.28	42.50	104.44
Broadcasting	4.61	42.11	102.11
LSD (0.05)	NS	NS	NS
CV (%)	11.50	2.30	3.60

Means followed by the same letter within a column within the same treatment category are not significantly different at 5% level of significance; CV = Coefficient of variation; LSD = Least significant difference

test crop. This variety is high yielding and popular among farmers in the area and performs well under a wide range of altitudes. The tef variety Quncho was developed from crossing between two parental tef lines Dukem (DZ-01-974) and Magna (DZ-01-196). The female parent (Ovule) DZ-01-974 (Dukem) is a high-yielding variety developed through pure line selection and released in 1995; however, because of the less attractive seed colour (pale white), its preference by farmers is very limited. On the other hand, the male parent (Pollen) DZ-01-196 (Magna) is an old improved variety developed by pure line selection and released in 1970 [18, 19]. DZ-01-196 has been popular for its very white seed colour, but its productivity has been relatively low (1.6–1.8 t ha^{-1}). Hence, a targeted cross was made between the two varieties, with the objective of selecting recombinants constituting the high yield of DZ-01-974 and the good seed quality (White seed) trait of DZ-01-196. Quncho was then developed as a single-seed descent-derived recombinant inbred line and, after a series of multi-environment yield tests in various major tef-growing regions of the country, it was officially released in 2006 [17].

Treatments and Experimental Design: The treatments consisted of factorial combinations of two sowing methods (Broadcasting and row sowing) and six seed rates (2.5, 5, 10, 15, 20 and 25 kg ha^{-1}). The 12 factorial treatment combinations were laid out in a randomized completely block design (RCBD) and replicated three times. The gross plot size was 2 m x 2 m (4 m^2) and the distance between plots and replications were 1 m and 1.5 m, respectively. For row sowing, the distance between rows was 20 cm and the seed rate for each plot was divided into equal proportions of 10 rows per plot based on weight and broadcast on the surfaces of each row.

Experimental Procedure: Fine seedbed suited for tef cultivation was prepared before sowing. Sowing of the seed was done on 30 July 2012. Fertilizers were applied at the rate of 60/60 kg ha^{-1} N/P_2O_5 in the form of Urea and DAP, respectively. The latter was applied at planting; Urea was applied as top dressing at tillering stage to satisfy the remaining nitrogen requirement as well as to minimize its loss through leaching and volatilization. The experimental field was hand-weeded as required during the growing season.

Data Collection and Measurement: The entire plots were used for collecting and measuring data on phenological and growth parameters. Tef plants were harvested from the whole plots to determine grain yield, 100-seed weight, shoot biomass, straw yield and harvest index. Individual plant parameters were determined from 10 randomly selected plants from the central parts of each plot.

Phenological Data: The following data were recorded.

Days to Seedling Emergence: The number of days that elapsed from sowing up to the date when 50% of the seedling emerged in a plot.

Days to Panicle Emergence: The number of days elapsed from the dates of seedling emergence up to the date when the tips of the panicles first emerged from the main shoot on 50% of the plants in a plot as determined by visual observation.

Days to Maturity: The number of days that elapsed from the date of sowing to the date when stems, leaves and floral bracts of 50% of the plants in a plot changed to light yellow colour as determined by visual observation.

Height and its Components, Tillering and Yield and Yield Component: The following growth parameters, yield and yield components were recorded at maturity.

Plant Height: Height of the plant was measured in centimetre from the base of the main stem to the tip of the panicle of the main shoot and recorded as the average of 10 randomly selected plants.

Culm Length: The length of the main shoot culm in cm from the base of the plant to the point of start of panicle branching taken on 10 random samples of plants from the central parts of each plot. Alternatively, the culm length is obtained by subtracting the panicle length from the plant height.

Panicle Length: Length of the panicles was measured in centimetre from the node where the first panicle branch starts to the tip of the panicle of the main shoot and recorded as the average of 10 randomly selected plants.

Main Panicle Weight: The average weight of the main shoot panicle at harvest in gram was measured on 10 randomly selected pre-tagged plants and the average was taken for analysis.

Number of Total Tillers and Productive Tillers: The total number of tillers (Panicle bearing and non-panicle bearing or non- productive) tillers and productive (Panicle-bearing) tillers were counted on randomly selected 10 plants per plot at dough stage to determine total as well as effective tillers.

Main Panicle Seed Weight: The average seed weight of the main shoot panicle at harvest in gram was measured on the basis of the average of 10 randomly selected pre-tagged plants.

1000-seeds Mass: The weight of counted 1000 seeds in gram was recorded at harvest in each respective plot using a sensitive balance.

Grain Yield: The weight of yield of grain was measured in gram after ten days of air-drying following harvest and converted into kg ha^{-1}.

Total Biomass: The weight of the total above ground biomass (Grain plus straw) of plants from the entire plots at harvest in kg was recorded in gram and converted into kg ha^{-1}.

Straw Yield: From the aboveground dry biomass, the grain yield was subtracted to get the straw yield on plot basis (g) and converted into kg ha^{-1}.

Harvest Index: The ratio of grain yield to total above ground (Shoot + grain) biomass was recorded from the entire plot.

Logging Index: Lodging is defined as the displacement of the aerial parts of the plants from the upright vertical position. The degree of lodging was assessed just before the time of harvesting by visual observation at GS-55 and GS-73 using the method of Caldicott and Nuttall [20]who described lodging index as the sum of the product of each scale of lodging (0-5) and its percentage divided by five. The lodging degree or angle of leaning was scored on the scales of 0-5 and 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. Each plot was divided into all the different 0-5 scores (Scales) based on the displacement of the aerial stem. For each degree of lodging, the percentage of proportion of each plot was then assessed. Each scale was multiplied by the corresponding percent given for each scale and the average of the product sum was taken to get the lodging index for each plot. The lodging index data collected were subjected to arcsine transformation according to Gomez and Gomez [21] for managing the possible error committed while guessing lodging percentage.

Data Analysis: All the data were subjected to analysis of variance (ANOVA) using SAS, version 9.1.3, general linear model (GLM) procedures [22]. Means were separated using the least significant difference test (LSD) at $p < 0.05$significant level.

RESULTS AND DISCUSSION

Effect of Sowing Methods and Seed Rates on Tef Crop Phenology: The main as well as the interaction effects of sowing method and seed rate did not influence the number of days required for seedling emergence. Good land preparation and absence of excess water may have contributed to the smooth and uniform germination of seeds in each of the plots. Seedling emergence was observed in most plots within four days (Table 1). The lack of significant effects of sowing method and seed rate on days to seedling emergence might be because germination of seeds mainly depends on the food reserve (Endosperm) of the seeds and soil factors, such as moisture, temperature and availability of oxygen rather than on sowing methods and seed rates. This suggestion is consistent with that of Jan *et al*. [23] that embryo grows at the expense of stored food materials and did not require any external nutrition.

Days to Panicle Emergence: The analysis of variance indicated that the number of days taken from seedling emergence to panicle emergence was significantly ($P \leq 0.05$) affected by seeding rate. In contrast, neither the main effects of sowing method nor the interaction effects of sowing method and seed rate had significant influence on days to panicle emergence. Thus, the number of days required for panicle emergence increased by 6% in response to decreasing the seeding rate from 25 kg ha^{-1} to 2.5 kg ha^{-1} (Table 1). Compared to the higher seeding rates (15, 20 and 25 kg ha^{-1}), the crop took significantly higher number of days for panicle emergence when it was planted at seeding rate of 2.5 kg ha^{-1}, which was in statistical parity with the number of days required for panicle emergence by plants sown at the low seeding rates of 5 and 10 kg ha^{-1}. In agreement with these findings, Read and Worder [24] found that heading in wheat and barley started earlier at higher seed rates indicating a hastening of heading due to influences on growth parameters under higher density. However, unlike the present findings, Sate [25] reported that, both seed rate and sowing method did not significantly influence the number of days required for panicle emergence of tef.

This finding indicated that, the time required for panicle emergence was prolonged in response to decreasing the seed rate. This could be ascribed to luxurious growth due to less stiff competition among plants for growth factors. This suggestion is in agreement with that of Hoshikawa [26] who also reported that higher planting density hastened early heading and flowering in rice by affecting the heading and flowering order within a plant, hill and population. The author further indicated that when the number of productive tillers per plant was small, the heading time was short by 4-5 days, but when the number productive tillers was large, more days were needed, example, about 10 days at the number of 30 panicles per plant.

Days to Maturity: Differences in the time of crop maturity are caused by the genetic makeup of the variety or by environmental conditions existing during their growth, grain filling or harvesting period of the crop [27]. Days to physiological maturity were significantly ($P = 0.01$) affected by the main effect of seed rates. However, this parameter was affected neither by the main effect of sowing methods nor the interaction effect of sowing methods and seed rates. Similar to its effect on days to panicle emergence, decreasing the seeding rate significantly prolonged days to maturity of the crop. Thus, plants grown at the seeding rate of 2.5 kg ha^{-1} matured significantly later than plants grown at the other seeding rates except plants grown at the seeding rate of 5 kg ha^{-1}, which statistically matured at the same time with plants grown at the seeding rate of 2.5 kg ha^{-1} (Table 1). Thus, the maturity time of plants grown at the seeding rate of 2.5 kg ha^{-1} was prolonged by about 11% compared to the maturity time of plants grown at the seeding rate of 25 kg ha^{-1}. Comparatively, the maturity times of plants grown at the seeding rates of 15, 20and 25 were low and in statistical parity. However, the maturity time required by plants grown at the seeding rate of 10 kg ha^{-1} was in the intermediate range (Table 1).

Corroborating the result of this study that plants grown at low seeding rates had prolonged maturity time whereas those grown at higher seeding rates had hastened maturity was reported by Getnet [28]. This author reported that maturity of triticale was earlier at the highest seed rate of 150 kg ha^{-1} than at lowest seed rate of (75 kg ha^{-1}). Use of higher seed rates especially at 25 and 20 kg ha^{-1} brought about early maturity of the tef crops. This could be due to the higher plant population density, which might have caused stiff competition among the plants and inducing them to complete their life cycle earlier. On the other hand, plants grown at the seeding rates of 2.5 and 5 kg ha^{-1}conditions took the longest time to achieve physiological maturity in this study. Therefore, the delay in physiological maturity of tef crops sown at lower rates in the present study might be attributed to luxurious growth and development that might have been caused by ample supply of growth factors due to less competition among the plants.

Effects of Sowing Method and Seed Rate on Plant Height, Its Components and Tillering

Plant Height: Plant height is an essential growth character directly linked with the productive potential of plants in terms of fodder and grain yield. An optimum

Table 2: Main plant height, panicle length, number of total and fertile tillers of tef as affected by sowing method and seed rates.

Treatment	Plant height (cm)	Panicle length (cm)	No. of total tillers plant^{-1}	No. of fertile tillers plant^{-1}
Seed rate (kg ha^{-1}) (Means over both sowing methods)				
2.5	113.20c	50.23	26.33a	23.83a
5	124.90ab	51.17	15.00b	12.83b
10	124.20b	51.00	12.00c	10.33c
15	126.20ab	51.98	9.83cd	8.17cd
20	126.90ab	52.68	8.00d	6.67d
25	128.55a	52.72	7.50d	5.83d
Mean	123.99	51.63	13.11	11.28
LSD (0.05)	3.95	NS	2.65	2.42
Sowing Methods (Means over all seed rates)				
Row sowing	125.44a	52.11	14.61a	12.83a
Broadcasting	122.55b	51.15	11.61b	9.72b
LSD (0.05)	2.28	Ns	1.53	1.40
CV (%)	2.70	5.40	16.90	17.90

Means followed by the same letter with in a column within the same treatment category are not significantly different at 5% level of significance. NS= non-significant; CV = Coefficient of variation; LSD = Least significant difference

plant height is claimed to be positively correlated with productivity of plants [29]. The analysis of variance revealed significant difference ($P \leq 0.05$) on main effects of sowing methods and highly significant ($P \leq 0.01$) on main effects of seed rates on plant height. However, the interaction effect of sowing methods and seed rates did not influence this parameter.

Increasing the seeding rate significantly increased plant height. The shortest plants were obtained from the seeding rate of 2.5 kg ha^{-1} whereas the tallest plants were obtained from the seeding rate of 25 kg ha^{-1}. Thus, on average, tef plants raised from the seeding rate of 25 kg ha^{-1} were taller than those raised at the seeding rate of 2.5 kg ha^{-1} by about 14%. However, the heights of plants grown at the seeding rates of 5, 15 and 20 kg ha^{-1} were all in statistical parity with the heights of plants raised at the seeding rate of 25 kg ha^{-1}. Similar to the present results, Hasan Kilic and Songul Gursoy [30] found that high seeding rate promoted plant height to a certain level at early stage of growth, while elongation was slightly depressed at the later stage of growth. Consistent with this result Oghalo [31] reported that increase population density also increased vegetative characters such as plant height, tiller numbers, leaves number and leaf length.

On the other hand, there was an increasing trend in plant height as the level of seeding rate increased from the lowest 2.5 kg ha^{-1}to the highest 25 kg ha^{-1}and the increment in height of the crop was from 113.21 to 128.5 cm. Plant height increased consistently with increasing seed rate from 124.2 cm at the seed rate of 10 kg ha^{-1} to 126.9 cm at the seed rate of 20 kg ha^{-1} (Table 2). Overcrowding due to increment of seeding rate per unit area might have caused aerial inter-plant competition between standing crops of tef for light and other growth factors thereby resulting in increase in vertical vegetative growth in height. On the other hand, plants grown using row sowing method showed significantly greater plant height than plants grown using the broadcasting method (Table 2).

This might be due to the overcrowding of plant population in row sowing which, in turn, might have caused an aerial inter-plant competition for light and space thereby promoting elongation of stems of the tef plants. This result is similar with the findings of Soomro *et al.* [32] who reported that the maximum plant height in wheat occurred at higher seed rate and row planting method. Likewise, Kakar *et al*. [33] also reported that plant height of wheat crops was significantly affected by seed rates and row sowing method.

Panicle Length: Panicle length is one of the major yield attributes of tef that is positively correlated with grain yield [34]. Panicle length measured at physiological maturity did not show significant difference due to the main effects of sowing methods, seeding rates and their interaction effects.

Number of Total and Productive Tillers: The number of total and particularly that of productive tillers per plant is the most important yield component because the final yield is mainly a function of panicle-bearing productive tillers per unit area. As the number of total and productive tillers per plant increases, the straw and grain yield of crops also increases. As the seed rate increases, the numbers of total and productive tillers decreases and *vice versa* [32].The analyses of variance showed significant ($P \leq 0.01$) main effects of both sowing methods and seeding rates on the number of both total and productive

Table 3: Interaction effects of sowing method and seed rate on culm length of tef

Treatment		
Sowing method	Seed rate (kg ha^{-1})	Culm length (cm)
Row	2.5	62.32e
	5	74.48bc
	10	74.46bc
	15	73.86bc
	20	79.86a
	25	75.02bc
Broadcast	2.5	63.63e
	5	73.01bc
	10	72.00cd
	15	74.62bc
	20	68.57d
	25	76.58ab
	Means	72.37
	LSD (0.05)	4.23
Sowing Methods (Means over all seed rates)		
	Row	73.33a
	Broadcast	71.40b
	LSD (0.05)	1.73
	CV (%)	3.5

Means followed by the same letter within a column within the same treatment category are not significantly different at 5% level of significance. NS= non-significant; CV = Coefficient of variation; LSD = Least significant difference

tillers per plant at dough stage. However, the interaction effects of sowing methods and seed rates did not significantly influence.

The result of this study indicated significantly higher mean number of both total and fertile tillers were obtained at the seed rate of 2.5 kg ha^{-1} as compared to the other seed rates tested (Table 2). Similarly, the number of total tillers increased by 100% in response to increasing seed rate from 5 kg ha^{-1} to 25 kg ha^{-1}. However, there was no statistically significant difference in the average numbers of total and productive tillers per plot between the seed rates of 10 and 15 kg ha^{-1}. On the other hand, at seed rate of 15, 20 and 25 kg $ha^{-1}$the numbers of both total and fertile tillers were comparable with each other at dough stage (Table 2).

Moreover, the present result demonstrated that as seed rate increased from the lowest (2.5 kg ha^{-1}) to highest (25 kg ha^{-1}), there was a consistent linear decrease in the number of tillers per plant (Table 2). This showed that under dense planting, there was a reduction in the overall growth and size of each plant and the number of total and fertile tillers became smaller. In agreement with this finding, Darwinkel [35] reported that reducing seeding rate resulted in the formation of more tillers and spikes per plant, but reduced grain yield per hectare. In contrast to this finding, however, Iqtidar *et al.* [36] reported that tillers per unit area in wheat increased with increase in response to sowing at the seed rates ranging from 50 to 200 kg ha^{-1} due to more number of established seedlings with the increased seeding rate. Contrary to this finding, Getnet [28] also reported that the higher seed rate produced the highest number of tiller than the plots sown at lower seed rates. Tef plants from row sowing method had significantly more numerous total tillers than plants under broadcasting. The total number of tillers-of row-sown tef plants exceeded the total tiller number of broadcast tef plants by 26%. Similarly, row-sown tef plants produced 32% higher number of productive tillers per plant than broadcast tef plants (Table 2).

Culm Length: Culm length was affected significantly ($P \leq 0.05$) by the main effects of both sowing methods and the interaction effects of sowing methods and seed rates. This parameter was also highly significantly ($P \leq 0.01$) influenced by the main effects of seed rates. The maximum culm length was recorded for the combined treatments of row-sowing at the seed rate of 20 kg ha^{-1} as compared to the interaction effect of the rest of treatments. However, the culm length obtained at the treatment combination of broadcasting and 25 kg seed rate was also in statistical parity with the culm lengths obtained at the aforementioned treatment combinations. On the other hand, the shortest culm length was recorded for the treatment combination of row-sowing at the seeding rate of 2.5 kg ha^{-1} as well as broadcasting at the same seeding rate (Table 3). The culm length recorded from plants established with the treatment combination of row-sowing and 20 kg seed rate exceeded the culm length of tef plants raised at the seeding rate of 2.5 kg ha^{-1} using the row-sowing method by about 28% (Table 3). In contrary to the present finding [37] reported that a significant reduction of culm length was observed with increasing plant density per unit area. This result indicated that as seed rate increased consistently the culm length also increased to certain extent caused by population density that triggered vertical competition among tef plants due to shading effect of one another and at the end resulted with culm length increment. Tef plants established through row sowing had longer culms (73.33 cm) than those established through broadcasting (71.40 cm) (Table 3). The culm length of plants established by row-sowing exceeded the culm length of plants established by broadcasting by 2.70%.

Table 4: Main panicle weight, main panicle seed weight, grain yield and thousand seed weight of tef as affected by sowing methods and seed rates

Treatment	Main panicle weight (g)	Main panicle seed weight (g)	1000-seed weight (g)	Grain Yield (kg ha^{-1})
Seed rate (kg ha^{-1}) (Means over both sowing methods)				
2.5	3.13a	1.81a	0.42a	1547d
5	2.57b	1.37b	0.39ab	1679cd
10	2.16c	1.22bc	0.36bc	1783c
15	2.08cd	1.09cd	0.36bc	2453b
20	1.73d	0.86e	0.35c	2371b
25	2.01cd	0.99de	0.34c	2702a
Mean	2.28	1.23	0.37	2089.14
LSD (0.05)	0.36	0.19	0.04	212.3
Sowing Methods (Means over all seed rates)				
Row	2.32	1.26	0.373	2167a
Broadcast	2.24	1.19	0.368	2011b
LSD (0.05)	ns	ns	ns	122.6
CV (%)	13.1	12.9	8.6	8.5

Means followed by the same letter within a column in the same treatment category are not significantly different at 5% level of significance. NS= non-significant; CV = Coefficient of variation; LSD = Least significant difference

Yield Parameters

Main Panicle Weight: The statistical analysis revealed that the main panicle weight was significantly ($P \leq 0.01$) affected by the main effect of seed rates but neither by the main effects of sowing method nor by the interaction effects of seed rate and sowing method (Table 4). The maximum tef panicle weights were recorded at the lowest seed rate of 2.5 kg ha^{-1}; this was closely followed by the main panicle weight obtained from the seeding rate of 5 kg ha^{-1}. The minimum panicle weights were recorded at the seed rates of 25, 20 and 15 kg ha^{-1}. The main panicle weight of tef plants established at the seeding rate of 2.5 kg ha^{-1} exceeded that established at the seeding rate of 25 kg ha^{-1} by 56%. In agreement with this finding, Ejaz *et al*. [38] reported that high seeding rate in wheat generally increases spikes per square meter, however, fewer and smaller kernels per spike can occur which results in little change in total grain yield. Similar to the present result Oghalo [31] also reported that main panicle weight in upland rice substantially decreased with increasing plant population.

This result indicated that main panicle weight decreased with the increasing seeding rate and ascertained the superiority of lower seeding rate against the larger seeding rates in enhancing of main panicle weight. When seed rate increased, planting density also increased substantially, leading to stiff competition among plants for growth factors. This may cause reduced absorption of water and nutrients by the plants and larger leaf area index that reduce reception of photosynthetically active radiation, leading to lower photosynthesis and assimilate production. Therefore, at denser plant spacing, leaves mutually shade each other, the upper leaves inhibiting the penetration of light to lower ones. A high leaf area index decreases the amount of assimilation in leaf as compared to its increase in total leaf area and affects partition of assimilation to economic organs that hinders proper filling of the grain which had direct influence on main panicle weight [39].

Main Panicle Seed Weight: Main panicle seed weight was significantly ($P \leq 0.01$) affected by the main effects of seed rate but significant neither by the main effects of sowing method nor by the interaction effects of the two factors (Table 4). Decreasing the seed rate consistently increased the main panicle seed weight. The highest main panicle seed weight was recorded for plants established at the lowest seed rate of 2.5 kg ha^{-1}, closely followed by the main panicle seed weights of plants raised at the seed rates of 5 and 10 kg ha^{-1}. The lowest main panicle seed weights were recorded for plants established at the seed rates of 25 and 20 kg ha^{-1}. The main panicle seed weight of plants raised at the seed rate of 10 kg ha^{-1} was in the intermediate range. In general, decreasing the seed rate from 25, 20, 15, 10 and 5 kg ha^{-1} to 2.5 kg ha^{-1}had increased the seed weight of main panicles by 83, 110, 66, 48 and 32%, in the order cited here respectively.

Corroborating the results of this study, Trinh *et al*. [40] reported that low seeding rate in rice generally increased panicle grain weight; however, fewer and smaller kernels per spike can occur which results in little change in total grain yield. Likewise Baloch *et al*. [41] also similarly reported that increased plant spacing considerably resulted in vigorous plant growth and caused a significant increase in panicle seed weight. This has due to plant density which had linearly increasing effect on the performance of individual plants. Compared to the given seed rates, plots treated with larger seed rate showed inferior performance with regard to both main panicle seed weight and main panicle weight in this finding. However, the increased main panicle seed weight in this finding could be due to vigorous growth of the above ground biomass mainly from high number of tillers, leaves and dry matter accumulation through more efficient use of growth resources due to less stiff competition. Thus, this is apparently attributed to proper vegetative and reproductive growth which may have ultimately led to the significantly enhanced panicle weight of plants per head.

Thousand Seed Weight: Thousand seed weight is an important yield determining component which is reported to be a genetic characteristic of a plant and therefore influenced least by the environmental factors [42]. However, the analysis of variance of the data showed significant ($p \leq 0.05$) variation in thousand seed weight for the main effect of seed rates but not for the main effect of sowing methods and the interaction effect of sowing methods and seed rates (Table 4).

Similar to the main panicle seed weight, decreasing the seed rate significantly increased 1000-seed weight of tef. Thus, the heaviest 1000-seed weight was obtained at the seed rate of 2.5 kg ha^{-1}, closely followed by the 1000 seed weights obtained at the seed rate of 5 kg ha^{-1}. The lightest 1000-seed weights were obtained in response to establishing the tef plants at the highest seed rates of 25 and 20 kg ha^{-1}. The 1000-seed weight obtained at the seed rates of 10 and 15 kg ha^{-1} lay in the intermediate range. The 1000-seeed weight obtained in response to establishing the crop at the seed rate of 2.5 exceeded that obtained in response to raising the plants at the seed rate of 25 kg ha^{-1} by 24%. When the plant density is low, a major part of the product of photosynthesis is retained in the shoot for the generation of shoot tissue and filling of the food stored by translocation of assimilation from the shoot to the grain. Under such conditions only a minor fraction of assimilates will be diverted to the root while the rest is utilized mostly for production of economic yield. But under high plant density, when the root cannot supply sufficient of the materials because of inadequate availability of nutrients, shoot growth slows. Because of these deficiency, few of assimilates formed by the existing leaf canopy can be used in the shoot whereas they will redirect most of the product to the root, encouraging its growth and thus improving the impaired root functions. Due to the aforementioned reasons, higher seed rate results increasing population density per unit area but resulted substantial decreasing of thousand seed weight. Consistent with the results of this study, Jan *et al*. [43] reported that as the seed rate was increased, the number of plants that emerged per unit area also increased but thousand seed weight was decreased for wheat.

In line with the above, difference in thousand seed weight due to seed rates were reported by Mazurek and Sabat [44]indicating that lower seeding rates gave higher thousand seed weight due to vigorous crop growth compared to higher rates that increased lodging index by enhancing plant height thereby reducing 1000-grain weight and final yield. This indicates that every seed from the lower seed rate might have greater weight as compared to every seed obtained from the higher seed rate.

Grain Yield: Grain yield ha^{-1} is a function of the integrated effect of the yield components which are influenced differently by growing conditions[45].The ANOVA of the grain yield data revealed significant ($P \leq 0.05$) on main effect of sowing methods and highly significant ($P \leq 0.01$) on main effect of seed rates. However, the two factors did not interact to influence this parameter (Table 4). In contrast to the above yield components, decreasing the seed rate generally led to decreased grain yields. Therefore, the highest grain yield was obtained in response to establishing the tef plants at the highest seed rate (25 kg ha^{-1}). This was closely followed by the grain yield obtained at the seed rates of 20 and 15 kg ha^{-1}. On the other hand, the lowest grain yields were recorded for tef plants established at the lowest seed rates of 2.5 and 5.0 kg ha^{-1}. The grain yields obtained from plants raised at the seed rate of 10 kg ha^{-1} was in the intermediate range. Thus, the grain yield obtained from plants established at the seed rate of 25 kg ha^{-1} exceeded the grain yields obtained from plants raised at the seed rates of 20, 15, 10, 5 and 2.5 by 14, 10, 52, 61 and 75%, respectively.

This finding is in agreement with that of Sewunet [46] who reported that higher rice grain yield was obtained at seed rate of 120 kg ha^{-1} than 60, 80 and 100 kg ha^{-1} seed rates in Fogera area in north-western Ethiopia. In contrast to the present findings, Fanuel *et al.* [47] conducted an experiment on participatory farmer's group evaluation of seed rates of tef and reported that most of the participating farmers preferred lower seeding rates when mixed with sand than higher seeding rates. Farmers' evaluation in both years indicated that seed rates of 5, 10, 15 and 20 kg ha^{-1} mixed with sand were preferred as the 1^{st}, 2^{nd}, 3^{rd} and 4^{th}, respectively. Likewise, Mitiku [12] contrary to the results in the present study, also reported that there was significant increase in yield and yield components of tef with decreased seed rates from the highest to the lowest (35, 30, 25, 20, kg ha^{-1}). The grain yield per unit area depends evidently on the performance of individual plants, panicle density as well as the total number of plants grown on the area [41].

In the present studies, the performance of individual plants grown with wider spacing was better as compared to the plants with narrower spacing. A balance has; therefore, to be brought between the performance of individual plants and the plants density per unit area for obtaining optimum crop yields.The results of the present experiment indicated that there was remarkable increment of yield with increased seeding rate. Plants grown with minimum seed rate had more area of land around them to draw plant nutrients, had more solar radiation to absorb for better photosynthetic process and hence performed better on individual plant basis than those established at high seed rate because of competition for growth factors. However, this study clearly indicated that the magnitude of total grain yield is not entirely dependent on the performance of individual plants but also on the performance of the total number of plants per plot and yield contributing parameters within the plant itself.

Row sowing led to significantly higher yields than broadcasting. Thus, tef plants established through row-sowing produced grain yields that exceeded the grain yield of plants established with broadcasting by 8% (Table 4). This might be due to the fact that larger panicle sizes (More grain number per panicle), much more number of effective tillers and less lodging were observed in row-sown tef plants than broadcast ones. This result is also in agreement with that of Tanveer *et al.* [48] who reported that more number of grains was produced per spike of wheat from row planting method over broadcasting. Similar to this finding, Mohammad *et al*. [49] also indicated that row sowing was superior to broadcasting for the essential yield components of wheat. In consistent with this finding Chen *et al*. [50] reported that Spring wheat grain yield was significantly affected by the row sowing and seeding rate and the author also further indicated that grain yield was increased with increasing of seeding rates from 108 to 215 seeds m^{-2}.The production of greater yielding components of tef can be attributed to improved light penetration and utilization because of the well-spaced plant population. Similarly, row-sown crops are considered superior in water use efficiency compared to broadcast ones.

Shoot Biomass: The total shoot dry matter produced by a plant as the result of photosynthesis and nutrient uptake, minus that lost by respiration is called biological yield [36]. Plants have the ability to compensate for low populations by producing more tillers. The dry matter of plants per unit area of land usually increases asymptotically as density increases. The asymptote extends over a wide range of densities, due mainly to the large plasticity of individual plant size, which determines that mean plant dry weigh declines to exactly compensate for increase in density; that is, proportionate reduction in dry weight occur as densities increase above the normal sown density [51]. The analysis of variance showed that total shoot biomass of tef was affected highly significantly (P=0.01) by the main effects of seed rates and significantly (P=0.05) by the interaction effect (P=0.05) of sowing methods and seed rates. However, the main effects of sowing method did not affect this parameter (Table 4).

Increasing the seed rate significantly increased shoot biomass yield. Plots sown to tef by broadcast sowing at the seed rates of 15 and 25 kg ha^{-1} and row sown at seed rate of 25 kg ha^{-1} resulted in significantly higher above ground shoot biomass yield than the other treatment combinations except that of row sowing at 20 kg ha^{-1}, which showed comparable mean shoot biomass yield. The minimum above ground shoot biomass yield was found with broadcast sowing at the lowest seed rate of 2.5 kg ha^{-1}. On the other hand, row sowing at 15 kg ha^{-1} and broadcast sowing at 20 kg ha^{-1} showed the second highest shoot biomass yield than 2.5, 5 and 10 kg ha^{-1} by both sowing methods but there was no significant variation between them on above ground shoot biomass yield. Similarly, 10 kg ha^{-1} with row sowing resulted in significantly higher biomass yield than both sowing methods at the lowest seed rate of 2.5 kg ha^{-1}and broadcast sowing of 5 and 10 kg ha^{-1}, with the exception of row sowing of 5 kg ha^{-1} which showed statistically equivalent mean biomass yield (Table 5).

There was no significant variation in the above ground shoot biomass yield in plots that were row-sown at the seed rates of 15 and 20 kg ha^{-1}and broadcast-sown at the seed rate of 20 kg ha^{-1}. Statistically comparable shoot biomass yields were obtained with row sowing of 2.5 and 5 kg ha^{-1}and broadcasting at the seed rate of 5 and 10 kg ha^{-1}. On the other hand, statistically similar results were also manifested between row sowing of 5 and 10 kg ha^{-1}. Likewise, statistically equivalent above ground shoot biomass yield was also found at seed rate

Table 5: Interaction effects of sowing method and seed rate on shoot biomass, straw yield, lodging percentage and harvest index of tef grown

Treatment					
Sowing method	Seed rate (kg ha^{-1})	Shoot biomass (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index (%)	Lodging (%)
Row	2.5	6563de	4913ef	25.21abc	40.98e
	5	7389cd	5658de	23.47de	42.70de
	10	8056c	6134cd	23.89cde	45.19cd
	15	9528b	7095bc	25.48ab	48.26c
	20	10750ab	8323a	22.54ef	55.79b
	25	11633a	8794a	24.44bcd	61.64a
Broadcast	2.5	5667e	4222f	25.55ab	42.90de
	5	6250de	4623ef	26.01a	44.04de
	10	6694de	5049ef	24.57abcd	48.07c
	15	11472a	9000a	21.55f	52.93b
	20	9570b	7255b	24.17bcd	61.64a
	25	11083a	8519a	23.27de	59.79a
	Means	8721	6632	24.18	50.33
	LSD (0.05)	1311.7	1049.8	1.48	3.44
Sowing Methods (Means over all seed rates)					
Row	8986.4	6820	24.17b	49.0944b	
Broadcast	8456.1	6445	24.19a	51.5611a	
LSD (0.05)	Ns	ns	0.61	1.40	
CV (%)	8.9	9.35	3.6	4.0	

Means in the same column within the same treatment category followed by different letters are significantly different as judged by LSD at P=0.05. NS= non-significant

of 2.5, 5 and 10 kg ha^{-1} both with broadcast sowing methods (Table 5). This might be due to the fact that biomass yield was directly related to plant height, panicle length, grain yield and tiller numbers which were directly influenced by seed rate, sowing method and their interaction as revealed in the result.

Similar to this result, Shakeel *et al*. [52] reported that the total dry matter and grain weight increment per unit area with decreasing in space up to a certain extent after which, there was no change or decrease depending on the character of the variety. On the other hand, Ejaz *et al*. [38] also reported that as seed rate increased in wheat, biological yield increased because higher seed rate resulted in higher seedling emergence per unit area and produced maximum biological yield. As seed rate increased correspondingly, crop establishment, plant height and number of plants per unit area also increased that substantially enhanced shoot biomass yield. This indicated that there is direct relationship between seed rate and biomass yield in influencing one another, increasing in one enables to increase on the other at certain extent. Similar to this result, Mitiku [12] found total above ground biomass increment with an increase in seed rate of tef. This might be due to increased number of plant population per unit area of land. Hence, the shoot biomass yield gained from the seed rate of 25 kg ha^{-1} over the smaller rate of 2.5 kg ha^{-1} which was 11358.3 kg ha^{-1} (185.8%) far beyond that obtained due to the lowest seed rate of 6114.6 kg ha^{-1} (53.8%).

Straw Yield: Straw yield was highly significant affected ($P \leq 0.01$) by the main effects of seed rate and by the interaction effect of seed rate and sowing methods ($P \leq 0.05$) while the main effects of sowing methods were not significant on this parameter (Table 4). The highest but statistically comparable values were obtained from broadcast sowing of 15 and 25 kg ha^{-1} and row sowing at the seed rates of 20 and 25 kg ha^{-1} than the rest of the treatments but the lowest straw yield was recorded under broadcast planting method of 2.5 kg ha^{-1}. Plots treated with broadcast sowing of 20 kg ha^{-1} resulted in the second highest shoot biomass yield compared to 2.5, 5 and 10 kg ha^{-1} for both sowing methods except row sowing of 15 kg ha^{-1} which showed statistically equivalent mean straw yield. Statistically comparable straw yield was found between 5 and 10 kg ha^{-1} with both row planting methods. On the other hand, statistically corresponding results were obtained with row sowing among seed rates of 2.5 and 5 kg ha^{-1} and broadcasting sowing at the seed rates of 5 and 10 kg ha^{-1}. Similarly, a significant difference in straw yield was not demonstrated with row planting among the seed rate of 2.5 kg ha^{-1} and broadcasting at the seed rate of 2.5, 5 and 10 kg ha^{-1}. In line with this result, Shakeel *et al*. [52] reported that, straw yield of rice was increased with increasing plant density. This might be due to the fact that biomass yield was directly related to plant height, panicle length, grain yield and tiller numbers which were directly influenced by seed rate, sowing method and their interaction as revealed in the result.

On the other hand, there was a trend of increment in straw yield as the seed rate increased from 2.5 kg ha^{-1} to 25 kg ha^{-1} except at 20 kg ha^{-1} which yields, lower straw yield as compared to the yield obtained in 15 kg ha^{-1}. The total straw yield was increased significantly by 4089.1 kg ha^{-1} when the seed rate runs from 2.5 to 25 kg ha^{-1}. A similar finding was reported by Sewenet [46] in rice that the highest seed rate produced higher straw yield than the lower rates.

Harvest Index: The relationship between total biological yields of crop was expressed in terms of harvest index which ultimately determines the ability of converting the dry matter into the economic yield [53]. The ANOVA of harvest index revealed highly significant ($P \leq 0.01$) effect due to the interaction effect of seed rate and sowing methods and significantly ($P \leq 0.05$) effect due to the main effect of seed rates. However, the main effect of sowing method was not significant on this parameter (Table 5).

The maximum harvest index was found with broadcast sowing of 5 kg ha^{-1}as compared to the interaction effect of the rest of treatments, with an exception to this was row sowing of 2.5 and 15 kg ha^{-1} and broadcast sowing at the seed rate of 2.5 and 10 kg ha^{-1} which showed statistically comparable mean harvest index while minimum harvest index was found with broadcast sowing of 15 kg ha^{-1}. On the other hand, statistically comparable harvest index were found with row sowing of 2.5, 10 and 25 kg ha^{-1} and broadcast sowing at the seed rates of 10 and 20 kg ha^{-1}. Similarly, there was no significant difference in harvest index with row sowing among seed rates of 5, 10 and 25 kg ha^{-1} and broadcast sowing at the seed rate of 10, 20 and 25 kg ha^{-1}. Likewise, row sowing at seed rates of 5, 20 and 25 kg ha^{-1} and broadcast sowing at seed rate of 25 kg ha^{-1} demonstrated equivalent mean harvest index. Lastly, comparable results were also observed with broadcast sowing of 15 kg ha^{-1} and row sowing at the seed rate of 20 kg ha^{-1} (Table 5).

The main effect of sowing method had non-significant effect on harvest index of the crop. On the other hand, the main effect of seed rate significantly affected by harvest index per plot and there were trends of increasing harvest index as seed rate was decreased from 20 to 2.5 kg ha^{-1} except at 25 kg ha^{-1}. These finding were in agreement with the results obtained by Zeng and Shannon [54] who reported that at high density, carbohydrate supply was limited because of shading among plants and the competition between shoot growth and panicle growth. The higher harvest index obtained in the lowest seed rate can be attributed to more light penetration through plant canopy and improved nutrient supply. However, Mollah *et al*. [55] reported that seed rate did not have significant effect on harvest index of wheat in bed planting condition.

Lodging Index: Lodging is the state of permanent displacement of the stems from their upright position [56]. It can be induced by both external and internal factors like wind, rain and morphological traits of the crops or by their interactions. Lodging is often not distributed uniformly throughout an affected field but may be scattered over certain sections or spots. Berry *et al.* [57] described the types of lodging as stem lodging and root lodging. The grain bearing organs of cereals are found at the top of the stems and therefore, exert a strain on the stalk especially under high wind or rain. It is one of the most important causes of yield loss in tef accounting for 20-25% of the total losses on average and almost all tef varieties are susceptible to lodging [58]. Lodging assessment was carried out during maturity stages. The data were transformed according to the arcsine transformation techniques described for percentage data by Gomez and Gomez [21] to stabilize the error.

Analysis of variance (Table 5) was performed using the transformed data. Lodging index was affected highly significantly ($P = 0.01$) by the main effects of both seed rates and sowing methods and significantly ($P = 0.05$) by the interaction effects of sowing methods and seed rates. The higher Lodging index was found under the maximum seed rate and both sowing methods. Accordingly the maximum lodging index, although not sever, was recorded with row sowing under the larger seed rate of 25 kg $ha^{-1}$and broadcast sowing at the seed rate of 20 and 25 kg ha^{-1} compared to possible combination of treatments but it showed lower with row sowing at lowest seed rate of 2.5 kg ha^{-1} (Table 5). Crops grown with broadcast sowing under the seed rate of 15 kg ha^{-1} gave similar lodging index with crops grown under 20 kg ha^{-1} with row planting method. On the other hand, row sowing at the seed rate of 10 and 15 kg ha^{-1} and broadcast sowing at the seed rate of 10 kg ha^{-1} showed mean of lodging index was statistically comparable. Similarly, statistically comparable results were also manifested with broadcast sowing of 2.5 and 5 kg $ha^{-1}$and row sowing at the seed rate of 5 and 10 kg ha^{-1} in influencing lodging index of tef (Table 5).

The higher lodging at higher seed rates under both planting methods might be due to the fact that the highest seed rate at both broadcast and row sowing method enhanced fast vegetative growth and succulent stem elongation of tef. That may have predisposed the plant to lodging. Similar to this finding, Mobasser *et al*. [59] reported that, higher planting density enhanced stem length and leaf area index in rice and played important role in increasing bending moment consequently causing increased lodging index. According to Seyfu [60] overall loss in grain yield due to lodging is estimated to be in the range of 11-22%. The deviation of this study might be due to the fact that rainfall ceased for seven consecutive days immediately after planting and caused all sown seeds in the field not to germinate fully. This may have that; the level of seed rate applied could not enhance the density of the crop to affect the lodging index.

Lodging is a major problem in the production of cereal crops because it causes decreases in yield and quality by reducing photosynthesis in the canopy, damages vascular bundles by bending or breaking stem and causes problem associated with mechanical harvesting [61, 62]. In a lodged plant community, the normal canopy structure is destroyed, resulting in reduced photosynthetic ability and dry matter production. Severe lodging prevents the transport of water, nutrients and assimilates through the xylem and phloem, resulting in a reduction in assimilates for grain filling [63]. High moisture levels in a lodged plant community may be favourable for fungal growth and for the development of diseases, which have detrimental effects on grain quality and appearance [61]. The grains of lodged plants may also germinate on the panicle, especially in cultivars with weak seed dormancy. As a result, lodging causes great losses in both grain quantity and quality. Furthermore, it also causes difficulties in harvest operations, increases demand for grain drying and consequently results in increased production cost [63].

CONCLUSION

Tef has existed in Ethiopia since the record history of the country and hence Ethiopia is the centre of origin and diversity of tef. The principal limitation of tef cultivation in the country is its low productivity and the national average grain yield is estimated 1.28 t ha^{-1}. One of the reasons for this low yield among other reasons is lack of appropriate sowing methods and utilization of improper seed rate. Hence, a field experiment was conducted during the main cropping season (June-November) of 2012 on Vertisols on-station at Debre Zeit Agricultural Research Centre with the objective of to assess the effect of seed rate and sowing methods on growth, yield and yield attributes of tef. Tef variety Quncho (DZ-Cr-387) was planted using combinations of two levels of sowing methods (Broadcast and row planting) and six levels of seeding rates (2.5, 5. 10. 15, 20 and 25 kg ha^{-1}). The experiment was laid out in RCBD design with factorial arrangements using three replications. All necessary agronomic and cultural practices were exercised during the growth period and necessary observations were recorded at various stages of crop growth and analysed by SAS, software program. Seeding rate significantly influenced days to panicle emergence and physiological maturity. At seeding rates of 25 kg ha^{-1}, tef crop showed earlier panicle emergence than the rest of the treatments with exception of 20 and 15 kg ha^{-1} which were statistically comparable. On the other hand, days to physiological maturity was significantly earlier at the highest seeding rate of 25 and 20 kg ha^{-1} than the rest of the treatments except the seeding rates of 15 kg ha^{-1}.

Seed rate of 2.5 kg ha^{-1}had produced significantly greater number of total and productive tillers, but it showed lower plant height than the rest of the treatments. The crop planted in rows manifested substantial number of tillers and higher plant height as compared to broadcast sowing method. On the other hand, seeding rate had highly significant effects on main panicle weight, main panicle seed weight and significant effects on thousand seed weight. In this result, the trend of main panicle weight, main panicle seed weight and thousand seed weight were decreased proportionally with seed rate. Likewise, statistically highly significant effects were also noted in grain yield due to both seed rates and sowing methods.

Significantly higher values were found for shoot biomass, culm length, straw yield and lodging index at higher seed rates under both sowing methods but increased seed rates showed low harvest index. The results indicated that shoot biomass, culm length, straw yield and lodging index showed linear increment with increased seed rates whereas the reverse was true in case of harvest index which manifested reduction with seed rate to a certain level.

In general, significant differences in grain yield and in most yields related parameters of tef were observed due to sowing methods and seeding rates; especially in case of 25 kg ha^{-1} which gave high and comparable yield at high seeding rate of 15 and 20 kg ha^{-1}. On the other hand, row sowing method had significant effects on growth parameters, yield and yield components of tef crop in terms of plant height, total tiller, fertile tiller and grain yield. Hence, it is difficult to make any definite conclusion based on the experiment of only one season and one location. However, as a tentative conclusion, seed rate at 25 kg ha^{-1} using row planting method can be suggested for the production of high grain and straw yield of tef on vertisols of Ada plains in Debre Zeit area. Overall, the present experiment has to be repeated over years and locations with similar agro-ecologies and soil types in order to reach at more conclusive recommendations for use by the tef growing farmers.

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