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Research article

Sowing methods and seeding rates effects on yield and yield components of Tef(*Eragrostis tef* [Zucc.] Trotter) at Adet, North West Ethiopia

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ABSTRACT

Tef is one of the most important staple cereal crops in Ethiopia. However, the production and productivity of the crop remain low due to lack of appropriate agronomic recommendations. Lack of optimum sowing methods and seed rates are key agronomic factors limit the productivities of the crop. Hence, field experiment was conducted to study the effects of seed rates and sowing methods on growth, yield and yield components of tef. The treatments contains factorial combination of two sowing methods (row and broadcast) and five seeding rates (5, 7.5,10, 12.5, and 15 kg ha^{-1}in randomized factorial complete block design with three replications. Days to heading, days to maturity, plant height, spike length, total number of tiller, total number of effective tiller, above ground dry biomass yield, grain yield and straw yield collected and subjected to analysis of variance using SAS system. The main effect seed rate significantly affect days to physiological maturity, plant height, panicle length, and straw yield and the maximum values of these parameters were recorded at the seed rate of 5 kg ha^{-1}. Similarly, number of total tillers, fertile tillers, total biomass, grain yield, and lodging percent were significantly ($p < 0.05$) influenced by interaction effect of sowing methods and seeding rates. The highest grain yield (2.301 kg/ha) and other growth parameters recorded at the interaction effect of 5 kg ha^{-1} of seed rate and row planting method compared to other treatments. Maximum net benefit (795,689.21ETB) with acceptable marginal rate of return (104.32) also recorded at the interaction effect of 5 kg ha^{-1} of seeding rate and row planting. Hence, 5 kg ha^{-1} seed rate with row planting method could be recommended for maximum yield of tef in Adet soil and climatic conditions.

1. Introduction

Tef (*Eragrostis tef* [Zucc.] Trotter) is one of the most important food cereal crops in Ethiopia, occupying about 23.85%of the cultivated land from the total area of cereals and 17.26% of the grain production (Abel Debebe, 2005). It is the major staple cereal crop and highly adapted to diverse agro-ecological zones including conditions marginal to the production of most of the other crops (Hailu Tefera and Seyfu Ketema, 2001). It is used for making *injera*, which is a staple and popular food in the national diet of Ethiopian (Abel Debebe, 2005). However, when grown as a cereal, farmers highly value its straw as source of animals feed, especially during the dry season (Seyfu Ketema, 1997). Tef straw, besides being the most appreciated feed for cattle, it is also used to reinforce mud and plaster the walls of house and local grain storage facilities called gottera (Seyfu Ketema, 1997). However the production and productivities of tef very low due to weed, inherent low yield potential, traditional sowing method, high seeding rate, frost, diseases, insects, management problems and soil-related constraints (Tareke Berhe, 2010). Among these, Seeding rates and sowing methods are greatly affecting the production and productivities of tef.

The small size of tef seed poses problems during sowing and indirectly also in 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 minimize weed infestation (SeyfuKetema, 1997).

When the plant density exceeds an optimum level, competition among plants for the light above ground and nutrients below ground becomes severe. So, plant growth slows down and the grain yield decreases (Baloch et al., 2002). There was a significant increase in yield components of tef with decreasing seed rate from highest to lowest. On

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the other hand, the lodging percentage of the crop increased by increasing the seed rate (Mitiku Melaku, 2008). It is, hence, necessary to determine the optimum density of plant population per unit area to obtain maximum yields.

Row sowing had more branches and better heights than broadcasting, which was broadcast resulting in higher competition for nutrients; while in row sowing there was wider space and thus relatively less plant competition for nutrients (Abebe Bekalu and Workayehu Tenaw, 2015). To improve production and productivity of tef planting methods (such as planting in rows rather than broadcasting) should be considered (ATA, 2013). Therefore, this research was initiated (i) to enhance tef productivity through optimization of the sowing method and seeding rate on the study area.

2. Materials and method

2.1. Description of the study area

The experiment was conducted at Adet Agricultural Research Center during 2018 main cropping season. It is located at 11° 17′ N latitude, 37° 28′ E longitudes and an altitude of 2193 masl. The average annual rainfall of the area is 1395 mm and the mean maximum and minimum annual temperatures are 25.7 and 10.7 °C, respectively. The soil type of study site is well-drained *Nitisol* with a pH of 5.99 (Adet agricultural research soil laboratory and meteorology unpublished data, 2018). Major crops grown in the area are tef, maize, wheat, barley, faba bean, and pea (see Figure 1).

2.2. Experimental material used for the study

Tef variety namely; Quncho (Dz-CR-387) have been used as planting material for this study. It is released by DebreZeitAgricultural Research Center in 2014. Quncho variety has a maturity period ranging from 86-151 days with an average yield potential of 2.5–2.7 tha^{-1} under research field, and altitudinal adaptation from 1800-2500 m above sea level.

2.3. Experimental treatment, design, and procedures

The treatments were two sowing methods (broadcast and row) and five seed rates (5, 7.5, 10, 12.5 and 15 kg ha^{-1}) factorial combined in a randomized complete block design (RCBD) with three replications. The size of the plot was 3*2 meter width and length, respectively. The net plot size was 2.6m*1.8m. Spacing between plots and blocks was 1m and 1.5m, respectively. Spacing for row planting method was 20cm between rows and has 15 rows per plot. Land preparation was done by tractor-plow and leveling was carried out by human power to ensure better seedbed for small seeds of tef. Sowing of the seed was done as treatment assigned on 10 July 2018. Fertilizers were applied at the rate of 40/60 kg ha^{-1} N/P_2O_5 in the form of Urea and NPS, respectively.

All phosphorus and 1/3rd of nitrogen source of fertilizer were applied at sowing time by drill technique in 20cm row spacing (for row planting method) and broadcast on surface soil for broad cast method using farmer practice and mixed with soil and the remaining $2/3^{rd}$ applied at 35 days after planting. The seed was uniformly drilled and broadcasted on the prepared plot based on methods and seeding rate. Two times hand weeding and cultivation and seedbed prevent erosion was carried out to keep the experimental plots free from weed and to provide better aeration.

2.4. Data collected and measurement

Each crop growth, yield, and yield components were measured from each net plot across the treatment level by using the following sampling procedures. Days to heading was recorded by counting the number of days from sowing up to the date when the tips of the panicles first emerged from the main shoot on 50% of the plant in a plot based on visual observation. Likewise, days to physiological maturity was recorded by counting the number of days from the date of sowing up to the date when 90% of the crop stands in a plot changed to light yellow color based on visual observation.

Plant height (cm) was measured ten randomly selected plants per plot were considered and measured from the base of the main stem to the tip

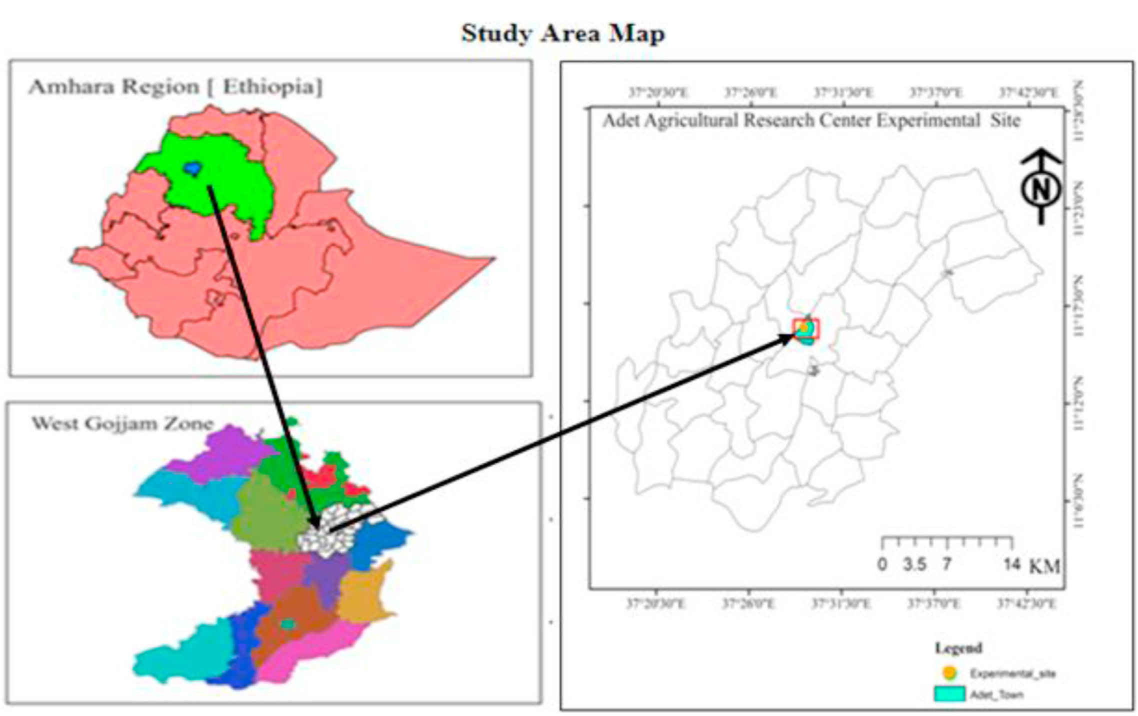

Figure 1. Map of the study map.

of the panicle. Likewise, panicle length (cm) was measured by selecting ten plants randomly per plot and measured from the node (the first panicle branch started) to the tip of the panicle.

Total and fertile tillers number was counted by selecting ten plants randomly in the central rows per plot. Lodging index was measured by observed 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 (1979), 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 in to 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. The crop was manually harvested from each net plot, sun-dried total aboveground crop biomass for one week and after that, total biomass were measured by weighing the sun-dried total aboveground crop biomass of the net plot. Threshing was done manually to separate the grains; the grain yield was measured by taking the weight of the grains from the net plot area. Straw yield was computed by subtracting grain yield from total aboveground sun dried biomass yield for knowing market price of straw. Harvest Index (%) was recorded by calculated as a ratio of the dry weight of the grain to dry weight of the total aboveground biomass yield and multiplied by 100.

2.5. Data analysis

The collected data were subjected to Analysis of variance (ANOVA) using SAS (version 9.0) software. Least Significant Difference (LSD) at 5% probability level was carried out for mean separation. Correlation analysis was carried out to study the nature and degree of relationship between yield and various growth and yield components. Correlation coefficient values (r) calculated and test of significance was analyzed using the Pearson correlation procedure found in SAS software. The mean grain and straw yield data were adjusted down by 10% and subjected to partial budget analysis (CIMMYT, 1988). The field price of 1 kg of grain (20 birr) and 1 tone of straw that farmers receive from local market price (3920 birr). The price of seed (33.15 birr kg^{-1}) and the price of labour making rows were taken based on 8.00 o'clock worked per day payment of 50 Birr (Man-day x 50 birr). The Gross benefit was calculated as grain yield (kg ha^{-1}) and straw (tone ha^{-1}) multiplied by grain and straw price that farmers receive for the sale of the crop (20 birr kg^{-1}) and straw (3920 birr per ton), respectively. Total costs that varied (seed and row making cost) for each treatments was calculated and treatments were ranked in order of ascending total variable cost and dominance analysis was used to eliminate those treatments costing more but producing a lower net benefit than the next lowest cost treatment. Net benefit was calculated by subtracting the total variable cost from the gross benefit. Then the marginal rate of return was calculated using the procedures described by CIMMYT (1988) as follows: MRR= (change in net benefit/change in total variable cost)*100.

3. Results and discussion

3.1. Phenological data

3.1.1. Days to heading

Days to 50% heading in tef did not show significant ($P > 0.05$) difference due to the main effects of sowing methods and seeding rate as well as their interaction.

3.1.2. Days to physiological maturity

Days to physiological maturity was significantly ($P < 0.05$) affected by the main effect of seed rate. Whereas the main effect of sowing methods and its interaction with seed rate was not significantly different on tef maturity. Sowing at 5 and 10 $kgha^{-1}$ seed rate delayed the crop physiological maturity by two days (133) over other treatments. 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 an ample supply of growth factors due to less competition among the plants. Physiological maturity of 7.5 kg ha^{-1} seed rate treatment has intermediate time required (132). Unlikely plants under 12.5 and 15 kg ha^{-1} seed rate required a shorter time to reach their physiological maturity (131) as compared to others (Table 1). This could be due to the higher plant population density, which might have caused strong competition among the plants and inducing them to complete their life cycle earlier. A similar finding was reported Refissa Leta (2012), in which treatments under lower seed rate sown in rows took a longer time to reach their physiological maturity.

3.2. Growth of tef as affected by sowing methods and seeding rate

3.2.1. Plant height

The result of the analysis of variance showed that plant height was significantly ($p < 0.05$) affected by the main effect of seeding rates. However, the main effect of sowing methods and the interaction effect did not show a significant difference. The highest plant heights (137cm) was recorded in seeding rates of 5kg $ha^{-1}$where as the shortest plant height (130.28cm) was recorded in 15$kgha^{-1}$, respectively (Table 2). The data indicated that when the seeding rate increase from 5kg to 15$kgha^{-1}$ heights of the plant become decreases The current finding is similar (Sate and Tafese, 2016) and (Refissa Leta, 2012) and (Shiferaw Tolosa, 2012) who reported that when the seeding rate increases from 5kg to 25$kgha^{-1}$, the plant height was decreased. A similar study, Sate and Tafese (2016) and Refissa Leta (2012) who reported that an increase in plant height due to row sowing and decreasing seed rate from 25 kg ha^{-1} to 10 kg ha^{-1} might be due to less intra-specific competition of plants for light and other growth resources such as nutrients and soil moisture.

3.2.2. Panicle length

The result of the analysis of variance showed that panicle length was significantly ($p < 0.05$) affected by the main effect of seeding rates. However, the main effect of sowing methods and the interaction effect did not show a significant difference in these parameters. The highest panicle length (46.6cm) was recorded in seeding rates of 5kg $ha^{-1}$where as the shortest panicle length (42.45cm) was recorded in 12.5$kgha^{-1}$, respectively. Seeding rates increase from 5kg to 15 kg ha^{-1} length of the panicle by 3.2 cm become decreases (Table 2). The increment of panicle length in the case of decreasing seed rate might be resulted due to the utilization of more growth resources by decreasing competition among plants.

This study is similar to Mitiku Melaku (2008) who found a higher panicle length of tef by decreasing the seed rate from 25 to 20 kg ha^{-1}. In the same way, Shiferaw Tolossa (2012) and Sate Sahle and Tafese Altaye (2016) reported there was also a significant increment in panicle length by decreasing the seed rate from 25 kg ha^{-1} to 10 kg ha^{-1}.

3.3. Number of total tillers and fertile tillers per plant

The analysis of variance indicated that the main effect of sowing methods and interaction effect of seeding rate and sowing methods were significant differences ($p < 0.05$) for total and fertile tillers number. The highest numbers of both total tillers (6.2) and fertile tillers (5.87), per plant were obtained at 5 kg ha^{-1} seeding rate and in row sowing method (Table 3). These might be due to the even distribution of seed in rows and good management is important to the wise use of nutrients, moisture, and aeration. The total tiller and fertile tiller number of row sown tef plants exceeded from total tiller number of broadcast tef plants by 26%, and similarly, seed sown in row was produced 32% higher number of fertile tillers per plant than broadcasted tef plants. The current finding is in line

Table 1. Effect of sowing methods and seeding rate on days to physiological maturity of tef at Adet during 2018 main cropping season.

Treatment	
(a) Sowing methods	**Days to maturity**
Row sowing	132.00
Broadcast	132.47
LSD (0.05%)	ns
(b) Seeding rate (kg)	
5	133[a]
7.5	132[ab]
10	133[a]
12.5	131[b]
15	131[b]
LSD (0.05%)	1.49
CV (%)	0.9

Means followed by the same letter within a column are not significantly different from each other at $P < 0.05$ according to Fishers LSD.

Table 2. The main effect of sowing method and seeding rate of tef on plant height and panicle length at Adet during 2018 main cropping season.

Treatment		
(a) Sowing methods	**Plant height (cm)**	**Panicle length(cm)**
Row sowing	132.66	44.15
Broadcast	133.81	44.32
LSD (0.05%)	ns	ns
(b) Seeding rate (kg)		
5	137[a]	46.6[a]
7.5	133.5[abc]	44.02[b]
10	134.48[ab]	44.72[ab]
12.5	130.92[bc]	42.45[b]
15	130.28[c]	43.4[b]
LSD (0.05%)	4.04	2.39
CV (%)	2.5	4.5

Means followed by the same letter within a column are not significantly different from each other at $P < 0.05$ according to Fishers LSD.

with, Lloveras*et al.,* (2001) who reported that a seed rate of tef affected the number of tillers. As the population increased competition for a resource also increased and results for less tillering (Farooq et al., 2006). Seeding 5 kg ha^{-1} with row sowing methods enhanced the number of tillers by 21.8, 19, 26.9, and 10.1% compared with sown in 7.5,10, 12.5 and 15 kg ha^{-1} respectively. The current study in line with (Abraham Reda, 2014) reported that the row sowing method had significantly more numerous total tillers than plants under broadcasting.

3.4. Yield related traits as influenced by sowing methods and seeding rates

3.4.1. Grain yield

Grain yield was highly significantly ($P < 0.01$) affected by sowing methods, seed rates and significantly ($p < 0.05$) by their interaction effects. The highest grain yield was obtained by combining the row sowing method with 5kgha^{-1} seed rate. Row sowing method 5kgha^{-1} seed rate is greater by 27.06 % greater as compared to the 15 kg ha^{-1} seed rate with broadcast methods. Seeding of 5kgha^{-1} with row sowing produced maximum tef grain yield (2.301tha^{-1}) followed by 7.5 kg ha^{-1} (2.22 t ha^{-1}) and 10 kgha^{-1} (2.21 t ha^{-1}) (Table 4). Plant height, panicle length, the tillers, total biomass, and straw yield directly contributed to the grain yield. Due to the positive contribution of these parameters, grain yield in 5 and 7.5 kg ha^{-1} seed rates were given a good yield. This might be due to the combined effects of row sowing method that facilitated better field management and lower seed rate that contributed to a lesser plant population by minimizing intra-specific competition for growth resources among plants.

This study showed increased seed rates from the lowest to the highest in row planting method the grain yield was decreased. However, in broadcasting method 10kg seeding rate was gave less yield from 12.5 and 15 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 (Baloch et al., 2002). Similar result was reported by Shiferaw Tolossa (2012) who reported that the combination of row sowing method and lower seed rate gave the highest grain yield of tef.

3.4.2. Biomass yield

Biological yield is the total of all dry matter produced through physiological and biochemical processes occurring in the plant system. Biological yield is an important factor because farmers are also interested in straw in addition to grain. The analysis of variance showed that biomass yield of tef was significantly affected ($P \leq 0.05$) by seeding rate and interaction of sowing methods and seed rates. But sowing methods did not show significantly different. The maximum biomass yield (13.65 tone) obtained on row sowing methods with 5kgha^{-1} seed rate, which is 18.58% more biomass than seeded at 15 kg ha^{-1} (Table 4). The lowest biomass yield (11.51 tone) was obtained on uses of higher seed rates with row sowing methods. From this result, it can be concluded that when the seeding rate decreases from 15 kg to 5 kg ha^{-1} the biomass yield was increased. This might be because 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 indicated in the result.

Table 3. Interaction effect of sowing methods and seeding rate on the number of tillers and productive tillers of tef at Adet in 2018 main cropping season.

Treatments			Sowing methods	
Seeding rate kg ha^{-1}	Tiller plant^{-1}		Fertile tiller plant^{-1}	
	Broadcast	Row	Broadcast	Row
5	4.27[bcd]	6.2[a]	4.2[bcd]	5.87[a]
7.5	4.40[bcd]	4.23[cd]	4.3[bcd]	4.13[bcd]
10	3.70[d]	5.03[abc]	3.33[d]	4.9[abc]
12.5	3.67[d]	4.53[bcd]	3.63[dc]	4.10[bcd]
15	3.77[cd]	5.57[ab]	3.5[d]	5.33[ab]
Sign	*		*	
LSD (0.05)	1.33		1.39	
CV	17.2		18.8	

Means followed by the same letter within a column are not significantly different from each other at $P < 0.05$ according to Fishers LSD.

Table 4. Interaction effect of sowing methods and seeding rate on grain yield, biomass yield and lodging of tef at Adet during 2018 main cropping season.

Treatment				
Sowing methods	Seed rate $kgha^{-1}$	Gy(t)	BY(t)	Lodging index (%)
Broadcast	5	2.16^{abc}	13.25^{ab}	31.67^{de}
	7.5	2.08^{abcd}	13.38^{ab}	22.5^{e}
	10	1.65^{f}	11.58^{c}	40.83^{cd}
	12.5	1.95^{cde}	11.99^{bc}	22.5^{e}
	15	1.81^{ef}	11.63^{c}	77.5^{a}
Row	5	2.30^{a}	13.65^{a}	22.5^{e}
	7.5	2.22^{ab}	13.52^{ab}	40.83^{cd}
	10	2.21^{ab}	12.80^{abc}	$50b^{c}$
	12.5	1.87^{def}	11.63^{c}	$50b^{c}$
	15	2.03^{bcde}	11.51^{c}	59.17^{b}
	Sign	**	*	***
	LSD (0.05)	0.247	0.15	17.10
	CV	7.17	7.19	24.05

Means followed by the same letter within a column are not significantly different from each other at $P < 0.05$ according to Fishers LSD; GY = grain yield; BY = biomass yield.

This study is in line with the finding of Bekalu Abebe and Arega Abebe (2016), who reported that tef which, sown 5$kgha^{-1}$ yielded 23.8% more biomass than seeded with 10, 15, 20, and 25 kg ha^{-1}). Sowing of tef with a small seed rate makes agronomic management easy and enables efficient utilization of applied nutrients (Hailu Tefera, 2008). The efficient utilization of applied fertilizer increased vegetative growth which, resulted in higher biomass production (Wakene Negash and Yifru Abera, 2013). The current results contradict the finding of Mitiku Melaku (2008), who reported that total aboveground biomass increment with an increase in seed rate of tef.

3.4.3. Harvest index

Harvest index is an indicator of dry matter partitioning towards the reproductive organs. As far as sowing methods and seeding rates are concerned, sowing methods was showed significant ($p < 0.05$) difference on the tef harvest index. Whereas seed rate, as well as its interaction of sowing methods and seeding rates, was not significant ($p > 0.05$) differences on harvest index on these parameters of tef. The higher result was obtained in row sowing methods (Table 5). Row sowing takes advantage of increasing harvesting index, which might help the plant to utilize growth resources (including solar radiation) in a better way to enhance fertile tiller numbers produce high grain yield. The current result is in line with the finding of Bekalu Abebe and Arega Abebe (2016), who reported that the harvest index was not affected significantly by seed rate and statistically not significant to each other's.

Table 5. Effects of seeding rates and sowing methods on harvest index of tef.

Sowing methods	Harvest index (%)
Row sowing	16.91^{a}
Broad cast	15.60^{b}
LSD (0.05)	1.1
Seeding rate (kg)	
5	16.60
7.5	16.04
10	15.77
12.5	16.18
15	16.68
LSD (0.05)	ns
CV (%)	8.86

Means followed by the same letter within a column are not significantly different from each other at $P < 0.05$ according to Fishers LSD.

3.5. Lodging index (%)

Lodging percentage was highly significantly ($P < 0.001$) affected by their interaction effect of sowing methods and seeding rates of tef. The highest lodging index was obtained from sown in broadcast sowing combined with 15 $kgha^{-1}$ seed rates followed by treatments sown in rows with 15$kgha^{-1}$ seed rates. The lower result was obtained from treatments sown in both sowing methods within lower seed rates (Table 4). The higher result of lodging percentage in the case of broadcast sowing method as well as at 15 kg ha^{-1} seed rate might be due to management problems and higher intra-specific competition to nutrients, moisture, and air among plants that led them to weak and succulent stems prone to strong wind and rainfall. The stem of row planted tef was better able to support the weight of the filled head of grain. The current result in line with the findings of Abraham Reda (2014) and Sate Sahle and Tafese Altaye (2016), who reported an increase of lodging percentage in tef crop in the case of broadcast sowing method as well as at 25 kg ha^{-1} seed rate.

3.6. Correlation analysis

Stepwise multiple linear correlation analyses were carried out using treatment means to determine the effects of method of sowing and seeding rates on the grain yield formation. Generally, the positive correlation of grain yield with all the agronomic parameters was observed except with the lodging index (Table 6). Days to physiological maturity of tef were positively correlated with plant height, panicle length, total and fertile tiller numbers, total biomass, grain yield, and straw yield but negatively correlated with harvest index and lodging percent. However, most parameters were not show significant correlation except plant height and panicle length. Plant height and panicle length correlated with total biomass and straw yield were significantly and positively but negatively correlated with harvest index and lodging percent.

Grain yield of tef was significant and positively correlated with total tiller ($r = 0.64$*), fertile tiller ($r = 0.73$*), total biomass (=0.85**) and straw yield ($r = 77$**). This indicates that grain yield significantly increases with the increase in total tiller, fertile tiller, total biomass, and straw yield. Straw yield had significant and positive correlation with plant height ($r = 0.68$*) and panicle length ($r = 0.65$*), and total biomass ($r = 0.99$***). This indicated that straw yield significantly increases with the increase in plant height and panicle length. Bekalu Abebe and Arega Abebe (2016), and Getahun Dereje et al. (2018), Grain and straw yields of tef were significantly and positively correlated with plant height and panicle length, similar results. Grain yield was not significantly

Table 6. Correlation coefficients among all parameters and yield components of tef studies on seed rate and sowing methods.

	DH	DM	PH	PL	TI	FT	TB	GY	ST	HI	LD
DH	1	0.43^{ns}	0.32^{ns}	0.43^{ns}	0.52^{ns}	0.46^{ns}	0.36^{ns}	0.29^{ns}	0.36^{ns}	-0.04^{ns}	-0.21^{ns}
DM		1	0.80**	0.69*	0.14^{ns}	0.20^{ns}	0.54ns	0.34ns	0.57ns	-0.10^{ns}	-0.03^{ns}
PH			1	0.60^{ns}	0.01^{ns}	0.07ns	0.67*	0.49^{ns}	0.68*	-0.01^{ns}	-0.28^{ns}
PL				1	0.47ns	0.50ns	0.65*	0.52^{ns}	0.65*	0.05^{ns}	-0.15^{ns}
TI					1	0.99***	0.34^{ns}	0.64*	0.25^{ns}	0.71*	-0.25ns
FT						1	0.43^{ns}	0.73*	0.32ns	0.78**	-0.26ns
TB							1	0.85**	0.99***	22^{ns}	-0.37ns
GY								1	0.77**	0.70*	-0.36ns
ST									1	0.09^{ns}	-0.35ns
HI										1	-0.19ns
LD											1

DH = days to heading; DM = Days to maturity; PH = Plant height; PL = Panicle length; TL = tiller numbers, FT = Fertile tillers; TB = Total biomass; GY = grain yield; ST = Straw yield; HI = Harvest index; LD = lodging.

Table 7. Partial budgets analysis as influenced by sowing method and seeding at Adet.

Treatments (seed rate with method)	Grain (kgha^{-1})	Straw (tone ha^{-1})	Growth Benefit (ETB)	Variable Costs (ETB)	Net Benefit (ETB)	Dominance	MRR (%)
5kg with B	1943	9.980	77981.6	165.75	77815.85		
7.5kg with B	1872	10.171	77310.32	248.63	77061.70	D	
10kg with B	1472	8.930	64445.6	331.50	64114.10	D	
12.5kg with B	1751	9.040	70456.8	414.38	70042.43	D	
15kg with B	1630	8.838	67244.96	497.25	66747.71	D	
5kg with row	2071	10.213	81454.96	1865.75	79589.21		104.32
7.5kg with row	1997	10.166	79790.72	1948.63	77842.10	D	
10kg with row	1987	9.536	77121.12	2031.50	75089.62	D	
12.5kg with row	1683	8.784	68093.28	2114.38	65978.91	D	
15kg with row	1823	8.537	69925.04	2197.25	67727.79	D	

B = broadcast, D = dominant.

difference with days to heading, days to maturity, plant height, panicle length and lodging index.

3.7. Partial budget analysis

Asa result of the present study, the costs for the different seeding rates and labour costs for row making were varied due to their rates and sowing methods. Accordingly, fertilizer application, weeding and harvest costs were similar for all treatment. To recommend the present result for the study area, it is necessary to estimate the minimum rate of return acceptable to producers in the recommendation domain. Based on partial budget analysis, maximum net benefit (795689.21 birr) with MRR (104.32), obtained from treatment combination of 5kg seed rate with row sowing (Table 7). The marginal rate of return of the non-dominated treatment (Table 7) shows that 5 kg ha^{-1} seed rate with row planting method record a positive marginal rate of return 104.32. According to CIMMYT, (1988) on-farm economic analysis of major cereals reported that MRR that is better when the MRR was >100 %. Generally from this experimental study conducted, one treatment of them record positive MRR. So that treatments that receive 5 kg ha^{-1} seed rate with row planting method record the highest MRR acceptance range and so, farmers should use this optimum seed rate and sowing method is cost-effective and economically feasible.

4. Conclusions and recommendation

Seeding rates and methods of sowing are greatly influencing the growth and yield of tef. Days to 90% physiological maturity, plant height, panicle length, and straw yield were significantly affected due to the main effects of seed rate while there were no significant effects due to the main effect of sowing methods. Harvest index significantly affected by sowing methods. Fertile tiller number per plant, biomass yield, grain yield, and lodging percent were affected by interaction effects of sowing methods and seed rates at the study area. Maximum grain yield were obtained from interactions of row planting and at lower seeding rate. An economic optimum grain yield was also obtained from interactions of row planting and at lower seeding rate (5 kg ha^{-1}). Thus, row planting combined with 5kgha^{-1} seed rate is suggested to improve productivity and net benefit of tef at Adet and similar agro-ecologies.

Declarations

Author contribution statement

Yechale Mengie: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Alemayehu Assefa; AbaynewJemal Jenber: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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