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Effects of Seed Rate and Row Spacing on Yield and Yield Components of Teff (*Eragrostis tef* [Zucc.] Trotter.) in Kiltu Kara Distirct of Western Ethiopia

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Authors' contributions

This work was carried out in collaboration among all authors. Author SK designed the study, performed the field experiment, generated data and wrote the whole manuscript. Author TA performed the statistical analysis, edited, read and approved the final manuscript. Author BN read and approved the manuscript.

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ABSTRACT

Teff is a major staple cereal crop in Ethiopia. However, its productivity is limited due to lack of appropriate sowing methods and utilization of improper seed rate are among the major once. Hence, a field experiment was conducted in Kiltu Kara District to determine the effects of seed rate and row spacing on yield and yield components of teff. Four levels of seed rates (10, 15, 20 and 25 kg ha^{-1}) and three rows spacing (15, 20 and 25cm) used and combined 12 treatments in total. The experiment was laid out as a randomized complete block design with a factorial arrangement in three replications. All yield components teff were significantly affected by different row spacing except straw yields of teff. The interaction of seed rate and row spacing showed significant difference for yield and yield components of teff. Significantly higher mean values of teff were found by the interaction of 10 kg seed rate ha^{-1} and 25 cm row spacing. Significantly higher panicle length

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(36.9), number of tillers per plant (5), number of productive tillers per plant (4) of teff was recorded from interaction of 10 kg seed rate ha^{-1} and 25 cm row spacing. Higher dry biomass (2591 kg ha^{-1}) and grain yields (1267 kg ha^{-1}) of teff were recorded from interaction of 10 kg seed rate ha^{-1} and 25 cm row spacing. Mean of highest harvest index (49%) of teff was recorded from interaction of 10 kg seed rate ha^{-1} and 25cm row spacing as compared to others. Significantly higher straw yields (1488 kg ha^{-1}) was recorded from interaction of 15kg seed rate ha^{-1} and 20 cm row spacing as compared to other treatment combinations. Therefore, the use of 10 kg seed rate ha^{-1} together with 25 cm row spacing was the optimum seed rate and row spacing and 10 kg ha^{-1} was profitable for the production of teff. To make definite conclusion further research for more seasons and location is required to give recommendation for the study area.

Keywords: Seeding rate; row spacing; growth; yield; yield components of teff.

1. INTRODUCTION

Teff (*Eragrostis tef* (Zucc.) Trotter) is a small cereal grain indigenous to Ethiopia; it belongs to the grass family Poaceae and is a C_4 self-pollinated crop [1]. It is endemic to Ethiopia and it has been widely cultivated in the country for centuries [2]. Teff performs well in medium altitude (1700- 2400 masl). The crop is found in most of the parts of the country especially in the highlands at the altitude ranging from 1800 to 2100 meters above mean sea level as it can be grown under diverse agroecological conditions. It is the major staple cereal crops and highly adapted to diverse agroecological zones including conditions marginal to the production of most of the other crops [3]. Teff is resistant to extreme water conditions, as it is able to grow under both drought and water logged conditions [2,4]. Combined with its low vulnerability to the attack of pests and diseases, it is mostly considered a low risk crop [4,5]. Seeds are broadcasted on a well ploughed soil and lightly covered with soil until germination and during the growing period, several weeding is often required [6]. It also provides over two-thirds of the human nutrition in the country [7].

However, despite its importance in Ethiopia, its productivity is low. In the year 2018 cropping season, yield was reported 1.76 t ha^{-1} [8]. Several detrimental factors explain its low yield. The lower productivity of teff might be due to its confinement to Ethiopia in terms of origin and diversification, which limits the chance of improvement like other cereals of international importance [9]. Other factors contributing to its low in productivity are lodging, method of planting and fertilizer application; the combined effect of those factors result up to 22% reduction in grain and straw yield [3]. Therefore, further improvement of product and productivity of teff is highly needed; as even improved varieties of teff are reported to yield only up to 2.2 t ha^{-1} on farmers' field [3] and the national average yield is about 1.76t ha^{-1} [8]. This low yield and productivity are mainly due to the crops including, additional farming system which is not supported by improved technologies such as proper sowing method and optimum seed rate. The very small seed size makes it difficult to control plant population density and even distribution of plants in standing field [10]. Overall, research on improved teff technologies has received limited international attention mainly because of the crop having only local importance [5]. However, some improved technologies have been identified to stimulate teff production and productivity. However, the improved teff varieties have not been widely accepted, seemingly associated with low consumer demand for the better performing varieties [2].

Teff improved cultivars, reduced the seed rate and row planting package is a new breakthrough in the country and also there is a blanket recommendation of row spacing (20cm) by Ministry of Agriculture for all teff varieties that have different growing habit and characteristics for different agroecologies and soil types and the agronomic components like row spacing and seed rate for different varieties should be optimized [11]. The blanket row spacing has limitation on the productivity of teff which is influenced by the fertility status of the soil and yield potential of specific variety [11]. The maximum grain yield can be obtained by application of 10 kg seeds per hectare with maintaining the 25 cm spacing between the rows. Larger seed rate application resulting in higher competition for nutrient uptake within plant population and their survival while use of less seed rate resulting into the less plant competition for available nutrient in the soil. Grain yield increased significantly high when the seed rate application decreased by10 kg ha^{-1}from the broadcasting method of sowing because due to the fact of more tillers in teff, as there are enough spaces found in the plant population [12]. [13,14] recommended a row spacing of 20 cm, while [15] concluded that the row spacing of 15 cm, on the other hand the row spacing of 15-30 cm for transplanting and drilling of growing teff to enhance its productivity [1]. The current production system cannot be satisfying the consumers' demand. This is because of number of agronomic constraints which includes lodging, low modern input utilization, and high post-harvest losses and also inappropriate sowing methods and improper use of seed rate etc. [1]. Use of proper seed rate enables to improve the production and productivity of teff through minimizing of lodging percent [16]. Row planting in tef is reported to have better yielding advantage over broadcast planting method. To minimize the problem of lodging on teff, low seed rate, row planting, late sowing and application of plant growth regulators were used [17,18].

In Kiltu Kara District the teff is cultivated as a major crop by the farmers among all the available crops in this particular area. In the area farmers were traditionally practicing and adopting the broadcasting method of sowing for teff cultivation and farmers are using high seed rate in between 25 to 50 kg per hectare with this method of sowing and there was not clear recommendation of row spacing to drill or transplant the teff seeds for different varieties. Furthermore, farmers were not even familiarized with the row planting technique and also, they were not even using the optimum recommended seed rate on their farm land for teff. It was also argued that this particular practice of sowing mostly reduces the yield because due to the uneven distribution of seeds in the field and that ultimately reflects into the increase in competition between the teff plants within the population for water, light, nutrients and makes weeding more difficult. Also, this sowing method was resulted in lodging due the heavy plant population within teff crops; which is the main cause for low yield of teff due to high plant density. Hence the study would fill the gap on impact of seed rate and row spacing of teff in agricultural productivity in the district. Therefore, the objective was to determine the effects of seed rate, row spacing and their interaction on yield and yield components of teff in Kiltu Kara District of Western Ethiopia.

2. MATERIALS AND METHODS

2.1 Description of the Experimental Site

The experiment was conducted on farmer's field after proper selection of appropriate site for the research in main cropping season during the year 2019 to 2020 in Kiltu Kara District of West Wollega Zone, Oromia Regional National State, Western Ethiopia. Kiltu Kara district is located at 517 km away from Addis Ababa capital city of the country (Fig. 1). It lies at the latitude of 9^{o}39'27" N and longitude of 35^{o}11'1''E and altitude of 1600-1800 m above the mean sea level. It has a warm humid climate with average minimum and maximum temperature of 14 and 28^{o}_{c} round the whole year, respectively. The area receives average annual rain fall of about 900-1200 mm in whole rainy season and its distribution pattern is unimodal. The rain periods cover from May to November across the year during the rainy season. The area is characterized by coffee dominant based farming system and crop-livestock mixed farming system in which cultivation of maize, sorghum, finger millet, barley, teff, Niger seed, haricot bean, field pea, soybean, banana, mango, Orange, avocado, sweet potato, yam, potato and anchote are the different crops grown in the area; among those maize, sorghum, finger millet, barley, teff and Niger seed are the major crops grown in the area [19].

2.2 Experimental Materials

Kena teff variety which is released from Bako Agricultural Research Center in the year 2008 was used as planting material. This variety was most suitable for the areas ranging from 1750 to 2000 meters above the mean sea level and also performs well in more than 1000 mm of rain fall in the whole year of rainy season. The seeds Kena was white in colour and small in size and reported more in production than the existing cultivars with little tolerance to the lodging. Kena teff variety released in 2015 with 98-124 days to maturity, white in colour and having yield potential of 1.9 to 2.4 t ha^{-1} on station and 1.72 to 2.2 t ha^{-1} on farmers' field.

2.3 Treatment and Experimental Design

The treatments 4 x 3 combinations were laid out in Randomized Complete Block Design with factorial arrangement in three replications. The four levels of seed rates as Factor A (10, 15, 20

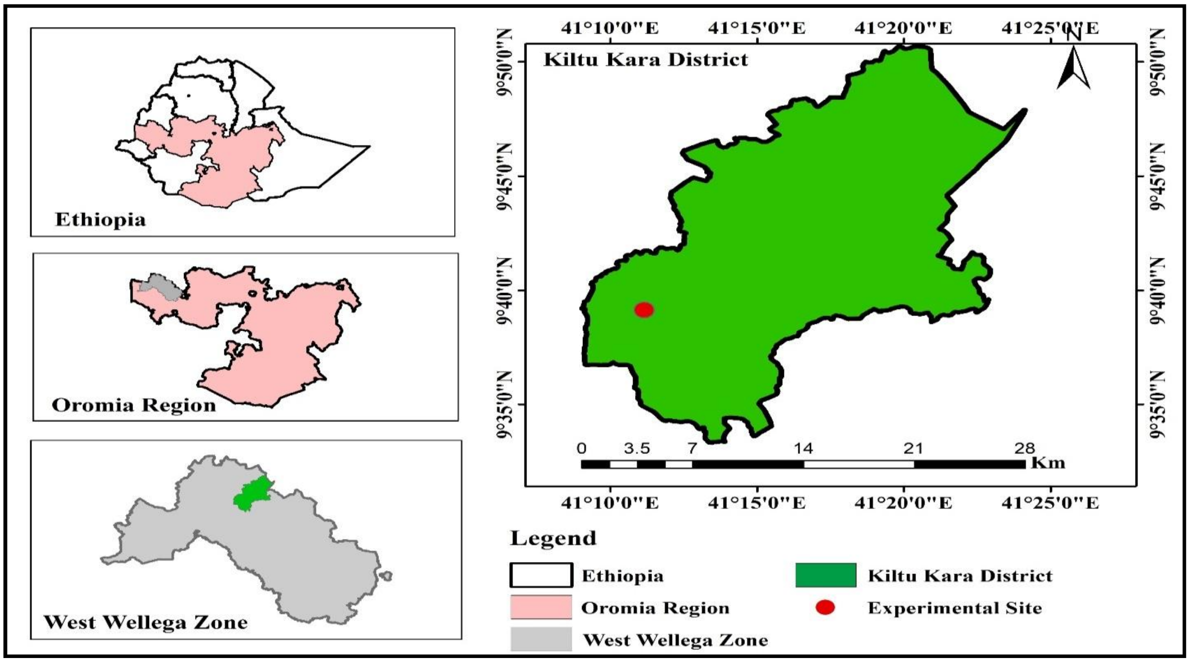

Fig. 1. Map of Study Area

and 25 kg ha^{-1}) and three row spacing as Factor B (15, 20 and 25 cm). 12 treatment combinations were replicated three times and randomly distributed. The plot size was 2mx2m =4 m^2 with 0.5m spacing between plots and 1m between blocks.

2.4 Experimental Procedures and Field Management

Clean and healthy seeds of Kena variety of teff were used for the planting purposes. The selected land for the research was laid out properly and was cleaned properly and ploughed 3-4 times before the sowing by using oxen and land was prepared to a plough depth of 25-30 cm during initial ploughing. Land was leveled properly with the traditional hoe with human labor. The rows were constructed according to the treatment combination. The recommended NPS fertilizer was applied at time of planting and the seed was sown manually by drilling method at the depth of 1-2 cm beneath the prepared land. Teff was planted approximately on dated 14 August 2019. All the agronomic package of practices required for teff such as hoeing, weeding and control measures for incidence of insects and pests were followed uniformly for all experimental plots.

2.5 Data Collected

Number of total tillers per plant: was counted at the time of physiological maturity by counting all the tillers from five randomly selected plants from the central rows of the net plot areas and average mean was considered.

Number of productive tillers per plant: was determined by counting the productive tillers from five randomly selected plants of central rows from net plot at maturity stage and the average mean was considered.
Panicle length**:** was measured from the node (where the first panicle branches emerged) up to the tip of the panicle for ten pre-tagged random samples of plants in the central rows of the net plot area with measuring scale and average mean was considered.

Dry biomass yield: was recorded at the maturity in the weight (kg) of the whole above-ground plant biomass including, leaves, stems, seeds and chaff of all the crops harvested from the net plot area after sun drying and was converted as kg ha^{-1}.

Grain yield: was measured from the grains harvested from the net plot area after threshing and sun-drying to about optimum moisture content and was converted to grain in kg ha^{-1}.

Straw yield: Was measured after threshing and measuring the grain yield; the straw yield was obtained by subtracting the grain yield from the total above-ground biomass yield.

1000 seed weight: Was determined by carefully counting a random sample of the small grains harvested from the net plot area and was weighed by using a digital balance

Harvest index: Was calculated by dividing grain yield by the total above ground biomass yield and multiplying by 100.

2.6 Data Management and Analysis

All the data collected was subjected to the analysis of variance (ANOVA) using SAS software version 9.4 programs [20]. The mean separation was carried out using Least Significant difference) test at 5% level of significance [21]. Pearson correlation analysis was performed to determine relations between phonological, growth parameter and yield and yield components of teff as influenced by seed rates and row spacing.

3. RESULTS AND DISCUSION

3.1 Total Tillers per Plant

The analysis of variance showed that total tiller per plant of teff was significantly (P < 0.05) affected by main effects both seed rate and row spacing and their interaction of the two main effects (Table 1). The mean total tiller per plant of teff was showed significant reduction as seed rates increased and vice versa (Table 1), where the use 10 kg seed ha^{-1} produced higher mean number of total tillers per plant (4) followed by 15kg seed ha^{-1} which produced of (3.5) total tillers. The use of 25kg seed ha^{-1} produced the lowest tillers per plant (2.8) (Table 1). There was also significant increment on mean total tillers per plant of teff by decreasing the seed rate from 25 to 10 kg ha^{-1}. The use of 10 kg seed ha^{-1} produced maximum number of total tillers per plant (4.9) of teff whereas the lowest number of tillers per plant (2.7) was recorded at 25 kg seed ha^{-1} (Table 1). The reduced number of tillers per plant in increased seed rate these might be due to maximum number of plant population in larger seed rates results for fewer tillers [22]. Because as the number of populations increase computation for resource also increase and results for less tiller [23]. Similarly, [24] in which productive tiller numbers decreased as seeding rate increased indicating negative effect of increased seed rate on number of tillers. This is due to lower access of plants to nutrients, water and light at higher seeding rate than lower seeding rates. Resulting from completion, as the number plant population increased competition for common resource is also increased. Also, [25], who reported broadcasted teff gave the lowest tiller number compared to row spacing. Similarly, [26] also reported, number of tillers m^{-2} of teff increased as seeding rate level decreased. In contrary, [27] reported that the higher seed rate produced the highest number of tiller than the plots sown at lower seed rates of teff.

The mean higher number of total tillers per plant (3.8) of teff was recorded in wider row spacing of 25 cm whereas the minimum number of total tillers per plant (3) teff was recorded in 15 cm row spacing (Table 1). Likewise, [28] that row sowing method, had significantly (P<0.001) affected the number of tillers. This is due to difficult situation for weed management results for crop-weed competition and productive tillers by broadcastings became less. Also, [29] reported that teff plants from row sowing method had significantly more numerous total tillers than plants under broadcasting. The total number of tillers-of row sown teff plants exceeded the total tiller number of broadcasting teff plants by 26%. Likewise, [30] reported that, total tiller number is a genetic character of teff, which is highly influenced by agronomic practices like inter row spacing. This is due to better access to space, nutrient, water and light in wider spacing than narrow spacing between rows and varietal characteristic is of major significance in the tillering ability of the crop [31].

The interaction of seed rate and row spacing was significantly (P<0.05) influenced mean number of total tillers per plant (Table 1). The highest mean number of total tiller (4.9) plant^{-1} was noted when 10 kg seed rate ha^{-1} and 25cm row spacing was used, followed by 10 kg seed rate ha^{-1} and 20cm row spacing which produced of (4.5) tillers per plant. While lowest mean number of total tiller (2.7) plant^{-1} was obtained from plots in which 25 kg seed ha^{-1} and 15cm row spacing (Table 1). The increase in mean total number tillers per plant due to increasing row spacing from 15cm to 25cm and decreasing seed rate from 25 to10 kg ha^{-1} might be due less intra-specific competition of plants for light and other growth resources such as nutrients and soil moisture. Similarly, [32] reported increased tillers per plant due to row sowing method and lower seed rate. Also,

[12] reported that decreasing the seed rate from the broadcast 25 to 10 kg ha^{-1} significantly maximize teff tillers per plant due to the fact that as there is enough space between teff plants.

3.2 Total Productive Tiller per Plant

The mean number of total 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, grain yield of crops also increases. As the seed rate increases, the numbers of total and productive tillers decrease and vice versa [33]. The total productive tiller per plant was significantly ($P < 0.05$) affected by both seed rate and row spacing and by the interaction of the two main effects (Table 2). The use of lower seed rates of teff was significantly increased the number of productive tillers per teff and vice versa (Table 1), where in, the use 10 kg seed ha^{-1} produced the maximum number of productive tillers per plant (3.4) followed by 15 kg seed ha^{-1} which produced of (2.6) productive tillers. There was also significant increment on total productive tillers per plant by decreasing the seed rate from 25 kg ha^{-1} to 10 kg ha^{-1}. As the mean value of total productive tillers per plant indicated in (Table 1), the use of 10 kg seed ha^{-1} produced maximum number of productive tillers per plant (3.4) whereas the lowest number of productive tillers per plant (1.7) was recorded at 25kg seed ha^{-1}. The productive tillers were higher at lower seed rate, when compared with higher seed rates. This might be due to decreased productive tillers with increase in seeding rate. Because by increasing seed rate per unit area, the inter plant competition for space, nutrient, moisture and sun light which results in lower productive tillers. Similarly, [26] reported that, number of effective tillers m^{-2} of teff increased as seeding rate level decreased. [29] reported that, row sown teff plants produced 32% higher number of productive tillers per plant than broadcast teff plants. 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 contrary, [34] who found maximum productive tillers at 200 kg ha^{-1} seed rates than at lower seed rates in wheat.

The analysis of the variance also showed that, maximum number of productive tillers per plant (2.85) was recorded in wider row spacing of 25 cm whereas the minimum number of tillers per plant (1.98) was recorded in 15cm a part row (Table 1). Likewise, [30] also reported that, row spacing had significantly influence number of effective tillers, in which number of effective tillers was significantly increased in response to increasing the row spacing from 15 to 30 cm for all varieties. This indicates that narrow row spacing had a negative effect on the production of high number of effective tillers. Likewise, [28] that row sowing method, had significantly ($P<0.001$) affected the number of tillers. This is due to difficult situation for weed management results for crop-weed competition and productive tillers by broadcastings became less.

The interaction of seed rate and row spacing was significantly ($P<0.05$) affected mean number of productive tillers per plant of teff (Table 1). The highest tiller number (4.2) was recorded when 10 kg seed rate $ha^{-1}$and 25cm row spacing was used, followed by 10 kg seed rate ha^{-1} and 20cm row spacing which produced of (3.73) productive tillers per plant. While lowest productive tiller (1.53) was noted from plots in which 25 kg seed ha^{-1} and 15cm row spacing (Table 1) .The increase in productive tillers per plant due to increasing row spacing from 15cm to 25cm and decreasing seed rate from 25 kg ha^{-1} to 10 kg ha^{-1} might be due less intra-specific competition of plants for light and other growth resources such as nutrients and soil moisture.

3.3 Panicle Length

Panicle length is one of the major yield attributes of teff that is positively correlated with grain yield [35]. The analysis of variance showed that panicle length of teff was significantly ($P < 0.05$) affected by both seed rate and row spacing and their interaction of two factors (Table 3). Mean panicle length of teff was decreased significantly in response to the increasing level of seed rate and decreasing row spacing (Table 9). The use of 25 kg seed ha^{-1} produced the shortest mean panicle length of (26.6 cm) of teff (Table 3). There was also significant increment in panicle length by decreasing the seed rate from 25 to 10 kg ha^{-1}. Likewise, [36] found higher panicle length of teff by decreasing the seed rate from 25 to 20 kg ha^{-1}.This difference between the highest and the lowest result of the panicle lengths at the measured time might be due to the optimum crop nutrients and wider row spacing leads to high intra -specific crops competition among each other. [37] Reported that panicle length of teff was significantly affected by the main effects of seed rates and increase in panicle length of teff decreasing seed rate from 25 to 10 kg ha^{-1} might be due less intra-specific competition of plants for light and other growth resources.

The highest panicle length (31.3 cm) was recorded in wider row spacing of 25cm whereas the shortest panicle length (27.6 cm) was recorded in 15 cm a part row (Table 3). Similarly, Shiferaw [26] reported increment of panicle length by row sowing method as compared to broadcast sowing method. In contrary, [38,39] reported that there was no significant effect of row spacing on spike length of rice and wheat.

The interaction effect of seed rate and row spacing had significantly ($P<0.05$) affect mean panicle length of teff (Table 3). The mean taller panicle length (36.9 cm) of teff was measured from the interaction effect of 10 kg seed rate ha^{-1} and 25 cm row spacing, followed by 10 kg seed rate ha^{-1} and 20 cm row spacing which was (33.7 cm) (Table 3). While shortest mean panicle length (26 cm) of teff was measured from the interaction effect of 25 kg seed rate ha^{-1} was used with 15cm row spacing (Table 9). The panicle length mean was observed to be in the range of 26 to 36.9 cm (Table 3). The increment of panicle length in the case of row space increment as well as decreasing seed rate might be resulted due to more space provided for the crop to utilize more growth resources by decreasing competition among plants.

3.4 Dry Biomass

The statistical analysis for dry biomass yield of teff was significantly ($P<0.05$) affected by row spacing, seed rate and by their interaction (Table 4). Lower seed rates significantly increased the dry biomass yield and vice versa (Table 4), where in, the use 10 kg seed ha^{-1} produced the maximum dry biomass yield (2494 kg ha^{-1}) followed by 15kg seed ha^{-1} which produced of (2421 kg ha^{-1}) dry biomass yield. The use of 25 kg seed ha^{-1} produced the lowest dry biomass yield (2071 kg ha^{-1}) (Table 4). There was also significant increment on dry biomass yield by decreasing the seed rate from 25 to 10 kg ha^{-1} as well (Table 4). In contrary, [36,40] who found that the total above ground biomass increment with an increase in seed rate of teff. Significantly higher mean dry biomass yield of (2408 kg ha^{-1}) teff was recorded in wider row spacing of 25 cm whereas the minimum dry biomass yield (2217 kg ha^{-1}) was recorded in 15 cm a part row (Table 4). [41] Also reported the significant increase in biomass yields of teff in response to decreasing the row spacing may be attributed to increased plant population.

The interaction of seed rate and row spacing was significantly ($P<0.05$) affected dry biomass yield (Table 4). The mean value of dry biomass yield of teff was higher with 10 kg seed rate ha^{-1} which produced maximum dry biomass yield (2591 kg ha^{-1}) of teff whereas the lowest dry biomass yield (1975 kg ha^{-1}) was recorded at 25 kg seed rate ha^{-1} of teff (Table 4). The highest (2591 kg ha^{-1}) dry biomass yield of teff was recorded from the drilling of 10 kg seed rate ha^{-1} and 25 cm row spacing followed by 10 kg seed rate ha^{-1} and 20cm row spacing (2529 kg ha^{-1}) (Table 4).Whereas the minimum (1975 kg ha^{-1}) dry biomass yield was recorded from the combination of 25 kg seed rate ha^{-1} and 15cm row spacing (Table 4). The increased in mean dry biomass yield of teff due to increasing row spacing from 15cm to 25cm 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 which resulted good proportion of vigor plant with maximum grain yield. The increase in biomass due to row sowing method and decreased seed rate in this research might be contributed from increased grain yield and the straw of the crop for aforementioned factors. The increase in dry biomass yield of teff might be due to the small seed rate and wider row space had made agronomic management easy and enable for efficient utilization of applied nutrients which facilitate plant growth. Similarly, [37] reported that biomass yield of teff was significantly affected by the main effects of sowing method and seed rate and higher biomass yield was obtained from row sowing as compared to broadcast sowing and a significant increase of dry biomass yield by decreasing the seed rate from 25 to 10 kg ha^{-1}.

3.5 Grain Yield

Mean grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of crop [42]. The mean tillers, total biomass and thousand seed weight directly contributed for the grain yield [27]. The mean grain yields of teff was significantly ($P< 0.05$) affected by both seed rate and row spacing and their interaction of the two main effects (Table 5). Lower seed rates significantly increased the mean grain yields of teff and vice versa (Table 5). Significantly higher (1123 kg ha^{-1}) mean grain yield of teff was obtained with 10 kg seed ha^{-1} followed by 15 kg seed ha^{-1} which produced (971 kg ha^{-1}) grain yields of teff. Higher seed rate (25 kg seed ha^{-1}) gave the lowest grain yield of teff (778 kg ha^{-1}) (Table 5). Significant increased mean grain yields of teff by decreasing the seed rate from 25 to 10 kg ha^{-1}. Likewise, [25] who reported that teff yield could be increased 3-4 folds by using drilling of 2.5-5 kg ha^{-1} of seed rate. Also, [43] found that lower seeding rates of teff gave the highest grain yield as compared to high seeding rates. Similarly, [28] also reported that low seeding rate increased grain yield due to increased yield components, which is in line with the present result. Likewise, [36] reported that there was significant increase in yield and yield components of teff with decreased seed rates from the highest to the lowest (35, 30, 25, 20, kg ha^{-1}). Similarly, [27] found seed rate had significant effect on grain yield of teff, in which teff sown with the rate of 5 and 10 kg ha^{-1} were increased grain yield by 45.15 % than seeded at the rate of 15, 20 and 25 kg ha^{-1}.Likewise, [16,25] reported that, significantly higher grain yield of teff from row planting at low seeding rate is more than two times higher than the national and regional [44]. Also reported that most of the participating farmers preferred lower seeding rates when mixed with sand than higher seeding rates. He further stated that 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 1st, 2nd, 3rd and 4th respectively. In contrary, [28] reported in contrast to the yield components, decreasing the seed rate generally led to decreased grain yields [29]. Also found that the highest grain yield was obtained in response to establishing the teff plants at the highest seed rate 25 kg ha^{-1} followed by yield obtained at the seed rates of 20 and 15 kg ha^{-1}. In contrary, [45] 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.

Significantly higher mean grain yields of teff (1017 kg ha^{-1}) were recorded in wider row spacing of 25cm whereas the minimum grain yields of teff (850 kg ha^{-1}) were recorded from 15cm rows spacing (Table 5). Similarly, [30] reported that grain yields of varieties increased across the increasing of the row spacing. This could be in wider spacing there is less competition for nutrients, moisture and light, more photosynthesis may be produced at the source and in turn translocate to the sink, thus resulting in higher yield [38]. In contrary, [39,46] reported that the narrow row spacing have higher grain yield than the wider row spacing in rice and wheat crops respectively. Mean grain yield of teff was significantly increased ($P<0.05$) from 733 to 1267 kg ha^{-1} with decrease the seed rate from the 25 to 10 kg ha^{-1} and increasing row spacing from 15 to 25 cm (Table 5). This could mainly be attributed to increase panicle length, productive tiller and plant height might have increased grain yield indirectly by increasing the number of grains per panicle.

The interaction effects of seed rate and row spacing had significant ($P < 0.05$) effects on mean grain yields of teff (Table 5). The highest mean grain yield of teff (1267 kg ha^{-1}) was recorded from drilling of 10 kg seed rate ha^{-1} with 25cm row spacing (Table 5). While the lowest grain yields (733 kg ha^{-1}) was recorded from the combination of drilling of 25kg seed rate ha^{-1} with 15cm of row spacing (Table 5). Similarly, [26] found that combination of row spacing method and lower seed that facilitated better field management and lower seed rate that contributed to lesser plant population by minimizing intra-specific competition for growth resources among plants. Also, [12] found that higher grain yield was obtained from 25cm row spacing with 10 kg ha^{-1}seeding rates with maximum mean grain yield of 1217 kg $ha^{-1}$and the lowest grain yield (974kg ha^{-1}) which was recorded from broad casting sowing methods of 25 kg ha^{-1} seeding rates [37]. Also reported that grain yield was significantly affected by sowing methods, seed rates and by their interaction and higher grain yield was obtained by combining row sowing method with 10 kg ha^{-1} seed rate

3.6 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 [47]. The analysis of variance was showed significant ($P< 0.05$) variation in mean thousand seed weight of teff for the two main effects (seed rate and row spacing) and by their interaction of the two main effects (Table 6). The mean thousand seed weight of teff significantly increased with reduced seed rates (Table 6), where in, the use 10 kg seed ha^{-1} produced higher thousand seed weight of teff (0.317 g) followed by 15kg seed ha^{-1} which produced of (0.294 g) thousand seed weight of teff. There was significant increment on mean total thousand seed weight of teff by decreasing the seed rate from 25 to 10 kg ha^{-1}. Similarly, [29] reported that decreasing the seed rate significantly increased 1000-seed weight of teff in which 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}. He further stated the lightest 1000-seed weights were obtained in response to establishing the teff plants at the highest seed rates of 25 and 20 kg ha^{-1}. The 1000 seed weight obtained at the seed rate of 10 and 15 kg ha^{-1} lay in the intermediate range. The 1000 seed 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^{-1} ha by 24%. The mean thousand seed weight of teff (0.301g) was recorded in wider row spacing of 25cm whereas the lightest thousand seed weight of teff (0.269g) was recorded in 15cm a part row (Table 6). Similarly, [48] found that row spacing, increased thousand grain weights by 44.56% as compared to broadcasting of seed in 25 kg ha^{-1}.

The interaction effects of seed rate and row spacing had significantly (P <0.05) effects on mean thousand seed weight of teff (Table 6). Higher thousand seed weight of teff (0.35g) was recorded from drilling of 10 kg seed rate ha^{-1} with 25cm row spacing. While the lightest mean thousand seed weight (0.26 g) was recorded from drilling of 25kg seed rate ha^{-1} with 15 cm of row spacing (Table 6). Mean thousand seed weight of teff was significantly increased (P<0.05) from 0.26g to 0.35g with decrease the seed rate from 25 to 10 kg ha^{-1} and increasing row spacing from 15 to 25cm (Table 6). This could mainly due to retained product of photosynthesis 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 in lower plant density of teff. 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 deficiencies, 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.

3.7 Straw Yield

The mean straw teff are indicated in Table 7. Mean straw yield of teff was significantly (P<0. 05) affected by seed rate and the interaction of the two main effects but non-significantly (P>0. 05) affected by row spacing (Table 7). Significantly higher mean straw yield of (1488 kg ha^{-1}) teff was recorded from the combination of drilling 15kg seed rate ha^{-1} and 20 cm row spacing. While the lowest mean straw yields (1243 kg ha^{-1}) was recorded from drilling of seed with 25 kg ha^{-1} and 15 cm row spacing (Table 7). There was more straw yield (1488 kg ha^{-1}) obtained from 15 kg seed rate ha^{-1} and 20 cm row spacing as compared to 25 kg ha^{-1} and 15 cm row spacing (Table 7).

The increased and decreased straw yield in different combination may be due to large and small seed rate that might have influenced vegetative growth in terms of plant height and number of tillers. Similarly, [36] reported that, more mean straw yield of teff was obtained from sowing teff in rows than broadcast in which better field management of crops might have favored the stem to accumulate more dry matter .Likewise, [49] also reported that row spacing might have influenced vegetative growth in terms of plant height and number of tillers per meter (effective and non-effective tillers) which resulted in increased straw yield. Similarly, [13,40] reported that lower seeding rate increased the straw yields. In contrary, [30] that reported increasing the row spacing significantly decreased the straw yields of all teff varieties.

3.8 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 [50]. Harvest index was significantly (P< 0. 05) affected by row spacing, seed rate and by their interaction (Table 8). Lower seed rates significantly increased harvest index of teff and vice versa (Table 8), where in, the use 10kg seed ha^{-1} produced higher harvest index of teff (45%) followed by 15kg seed ha^{-1} which produced of (40%) harvest index of teff. Similarly, [10] reported that, higher harvest index was obtained by reducing seed rate in teff. This might be because of the row spacing in row sowing method that might have reduced inter-specific competition and helped the crop to utilize growth resources in a better way to improve grain filling.

Also, [51] 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. In contrary, [52] reported that seed rate did not have significant effect on harvest index of wheat in bed planting condition.

Significantly higher mean harvest index of (42%) teff was recorded in wider row spacing of 25cm whereas minimum harvest index of (38%) teff was recorded in 15cm a part row (Table 8). Likewise, [49] reported that sowing of 5 kg ha^{-1} by row spacing of teff had 3.29% greater harvest index than broadcasting of teff at 25 kg ha^{-1}. Likewise, [30] also reported the wider row spacing generally increased the harvest index, which may be attributed to increased utilization of available sunlight for production of higher dry matter production and yield and also similar result was reported by [53].

The interaction of seed rate and row spacing indicated that , higher (49%) harvest index of teff was recorded from sowing seed by 10 kg ha^{-1} with 25 cm row spacing and minimum (37%) harvest index teff was recorded from drilling of seed by 25 kg ha^{-1} with 15 cm row spacing (Table 8). Significantly increasing trend of harvest index as seed rate was decreased from 25 to 10 kg ha^{-1} and as row spacing was increased 15 to 25 cm (Table 8).

3.9 Pearson Correlation of Yield and Yield Component of Teff Due to Seed Rate and Row Spacing

Correlation analysis between yield and yield components of teff revealed strong and positive associations between some components (Table 9). There were significantly positive correlation coefficients between dry biomass yield with total tiller (0.44), productive tiller (0.59) and harvest index (0.59). There were also highly significantly positive correlation coefficients between dry

Table 1. Main and interaction effect of seed rate and row spacing on total tiller per plant of teff in Kiltu Kara district

Seed Rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	3.3^{cde}	4.5^{ab}	4.9^{a}	4.2^{a}
15	3.1^{cde}	3.6^{cd}	3.9^{bc}	3.5^{b}
20	3.1^{de}	3.3^{cde}	3.5^{cd}	3.3^{bc}
25	2.7^{e}	2.9^{de}	3de	2.8^{c}
Mean	3^{b}	3.6^{a}	3.8^{a}	
	Seed rate	**Row spacing**	**Seed rate X Row spacing**	
LSD (5%)	0.37	0.4253	0.74	
CV (%)	12.53			

Means followed by different letter(s) in a column and rows are significant at 5% level of Probability

Table 2. Main and interaction effect of seed rate and row spacing on number of productive tillers per plant of teff in Kiltu Kara district

Seed Rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	2.33^{e}	3.73^{b}	4.2^{a}	3.4^{a}
15	2.2^{efg}	2.8^{cd}	2.93^{c}	2.6^{b}
20	1.87^{fgh}	2.27^{ef}	2.47^{de}	2.2^{c}
25	1.53^{h}	1.73^{h}	1.8^{gh}	1.7^{d}
Mean	1.98^{b}	2.63^{a}	2.85^{a}	
	Seed rate	**Row spacing**	**Seed rate X Row spacing**	
LSD (5%)	0.2644	0.229	0.46	
CV (%)	10.87			

Means followed by different letter(s) in a column and rows are significant at 5% level of probability

Table 3. Main and interaction effect of seed rate and row spacing on mean panicle length of teff in Kiltu Kara district

Seed rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	28.6^{de}	33.7^{b}	36.9^{a}	33.1^{a}
15	28.4^{edf}	29.8^{cd}	32.4^{bc}	30.2^{b}
20	27.2^{ef}	28.3^{def}	28.7^{ed}	28.1^{c}
25	26^{f}	26.9^{ef}	27^{ef}	26.6^{c}
Mean	27.6^{c}	29.68 ^{b}	31.3^{a}	
	Seed rate	**Row spacing**	**Seed rate X row spacing**	
LSD (5%)	1.49	1.3	2.6	
CV (%)	5.2			

Means followed by different letter(s) in a column and rows are significant at 5% level of Probability

Table 4. Main and interaction effect of seed rate and row spacing on dry biomass yield of teff in Kiltu Karra district

Seed Rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	2363^{cd}	2529^{ab}	2591^{a}	2494^{a}
15	2325de	2457^{abcd}	2481^{abc}	2421^{a}
20	2204^{ef}	2314^{dc}	2387^{bcd}	2302^{b}
25	1975^{g}	2063^{fg}	2175^{fe}	2071^{c}
Mean	2217^{b}	2341^{a}	2408^{a}	
	Seed Rate	**Row spacing**	**Seed rate X row spacing**	
LSD (5%)	87	76	151.1	
CV (%)	3.8			

Means followed by different letter(s) in a column and rows are significant at 5% level of probability

Table 5. Main and interaction effect of seed rate and row spacing on grain yield of teff in Kiltu Kara District

Seed rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	926^{ed}	1178^{b}	1267^{a}	1123^{a}
15	901^{ef}	969^{d}	1042^{c}	971^{b}
20	842^{fgh}	884^{efg}	936de	887^{c}
25	733^{i}	775^{hi}	825^{gh}	778^{d}
Mean	850^{c}	952^{b}	1017^{a}	
	Seed rate	**Row spacing**	**Seed rate X row spacing**	
LSD (5%)	39	34	68	
CV (%)	4.28			

Means followed by different letter(s) in a column and rows are significant at 5% level of probability

biomass yields of teff with plant height (0.67), panicle length (0.71), thousand seed weight (0.74), grain yield (0.86) and straw yield (0.61). Positively significant associations were observed between grain yield with total tiller (0.60) and highly significant positive correlation with productive tiller (0.73), panicle length (0.85), thousand seed weight (0.87) and harvest index (0.92). Highly significant, positive correlation coefficients were observed between harvest index with total tiller (0.61), productive tiller (0.71), panicle length (0.79) and thousand seed weight (0.79) (Table 9). Highly significant, positive correlation coefficients were observed between thousand seed weight with productive tiller (0.61), panicle length (0.85) and positively with total tiller (0.49). Positively significant correlation coefficients were observed between panicle length with total tiller (0.61) and productive tiller (0.68). Highly significant, positive correlation coefficients were observed between productive tiller with total tiller (0.85). Similarly,

[30] reported that grain yield had significant positive correlations with total number of tillers, number of effective tillers, and strong correlation with harvest index. Also, [14] reported that grain yield was positively correlated with number of tillers per plant. Similarly, [35] reported that panicle length is one of the major yield attributes of teff that is positively correlated with grain yield. Likewise, [49] found grain yield was positively and significant (P<0.001) associated with number of tillers and panicle length and thousand seed weight. Yield and yield component of teff had strongly positive relationship with grain yield of teff that indicated yield components of teff directly influenced the grain yield of teff.

Table 6. Main and interaction effect of seed rate and row spacing on thousand seed weight of teff in Kiltu Kara district

Seed Rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	0.28^{de}	0.32^{b}	0.35^{a}	0.317^{a}
15	0.27^{ef}	0.3^{cd}	0.31^{bc}	0.294^{b}
20	0.27^{ef}	0.27^{ef}	0.28^{ed}	0.274^{c}
25	0.26^{f}	0.26^{ef}	0.27^{ef}	0.263^{c}
Mean	0.269 ^{c}	0.289 ^{b}	0.301^{a}	
	Seed rate	**Row spacing**	**Seed rate X row spacing**	
LSD (5%)	0.01	0.01	0.02	
CV (%)	4.2			

Means followed by different letter(s) in a column and rows are significant at 5% level of probability

Table 7. Main and interaction effect of seed rate and row spacing on straw yield of teff in Kiltu Kara district

Seed rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	1437^{abc}	1352^{abcd}	1324^{bcd}	1371^{ab}
15	1424^{abc}	1488^{a}	1439^{ab}	1450^{a}
20	1363^{abcd}	1430^{abc}	1451^{ab}	1414^{a}
25	1243^{d}	1288^{cd}	1350^{abcd}	1293^{b}
Mean	1367	1389	1391	
	Seed rate	**Row spacing**		**Seed rate X row spacing**
LSD (5%)	87	NS		150.7
CV (%)	6.4			

Means followed by different letter(s) in a column and rows are significant at 5% level of probability

Table 8. Main and interaction effect of seed rate and row spacing on harvest index of teff in Kiltu Kara district

Seed rate (kg ha^{-1})	Row spacing (cm)			Mean
	15	20	25	
10	39^{bc}	47^{a}	49^{a}	44.9^{a}
15	39^{bc}	39^{bc}	42^{b}	40.1^{b}
20	38^{c}	38^{c}	39^{bc}	38.6^{bc}
25	37^{c}	38^{c}	38^{c}	37.5^{c}
Mean	38.3^{b}	40.5^{a}	42.1^{a}	
	Seed rate	**Row spacing**	**Seed rate X row spacing**	
LSD (5%)	1.96	1.69	3.39	
CV (%)	4.97			

Means followed by different letter(s) in a column and rows are significant at 5% level of probability

Table 9. Pearson correlation of growth, yield and yield component of teff due to seed rate and row spacing

	TT	PT	PL	TSW	HI	GY	SY	DBM
TT		0.85**	0.61**	0.49*	0.61**	0.60*	-0.07	0.44*
PT			0.68**	0.61**	0.71**	0.73**	0.01	0.59*
PL				0.85**	0.79**	0.85**	0.06	0.71**
TSW					0.79**	0.87**	0.09	0.74**
HI						0.92**	-0.27	0.59*
GY							0.12	0.86**
SY								0.61**
DBM								

** and ** = significant at the 0.05 and 0.01 probability level, TT=Total Tiller, PH=Plant height, PT= Productive Tiller per plant= Panicle Length, TSW=Thousand seed weight, HI=Harvest Index, GY=Grain yield, SY= Straw Yield, DBY= Dry biomass yield*

4. CONCLUSION

Seed rates significantly improved all yield and yield components of teff except. Mean panicle length, total tiller per plant, productive tiller per plant, dry biomass, grain yields, thousand seed weight and harvest index of teff were significantly improved with row spacing but had no significant effect on days to emergency and straw yields. The interaction of seed rate and row spacing was showed significant difference for panicle length, total tiller per plant, productive tiller per plant, dry biomass, straw yields, grain yields, thousand seed weight and harvest index of teff. Significantly higher values of teff were found using 10 kg seed rate ha^{-1} and 25 cm row spacing. Lower seed rate and wider row spacing was significantly improved yield and yield components of teff. Therefore, use of 10 kg seed rate ha^{-1} and 25 cm row spacing can be suggested for the production of teff in Kiltu Kara District. Thus, to give conclusive recommendation further research over location and years should be conducted.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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