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Effects of Seed Rate and Row Spacing on Phenology, Growth, Yield and Economic Feasibility of Teff (*Eragrostis tef* [Zucc.] Trotter.) Production in Kiltu Kara District of Western Ethiopia

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Abstract: Teff is a major staple cereal crop in Ethiopia and its low productivity due to lack of appropriate sowing methods and utilization of improper seed rate are among the major once. This in view a field experiment was conducted to determine the effects of seed rate and row spacing on phenology, growth, yield and economic feasibility of teff in Kiltu Kara District of Western Ethiopia during 2019/2020 cropping season. 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. Different seed rates significantly affected all phenology, growth and yield of teff except days to 50% crop emergency of teff. The interaction of seed rate and row spacing showed significant difference for all parameters of teff except days to 50% emergency. Significantly higher mean values of teff were found by the interaction of 10 kg seed rate ha^{-1} and 25 cm row spacing. The highest grain yield (1267 kg ha^{-1}) of teff was recorded from interaction of 10 kg seed rate ha^{-1} and 25 cm row spacing. The highest net benefit (EB 41437 ha^{-1}) and value to cost ratio EB 81 per unit of investment was obtained from sowing of 10 kg ha^{-1} seed rate of teff. 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 give definite conclusion further research for more seasons and location is required for the study area.

Key words: Plant Height・Seeding Rate・Row Spacing・Growth・Yield・Teff

INTRODUCTION

Teff (*Eragrostis tef* (Zucc.) Trotter) is a small cereal grain indigenous to Ethiopia and is a C_4 self-pollinated crop [1]. Teff is an allotetraploid (2n = 4x = 40) crop belonging to the grass family *Poaceae* and it is among the major cereals of Ethiopia [2]. It is endemic to Ethiopia and it has been widely cultivated in the country for centuries [3]. 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 [4]. It has the largest value in terms of both production and consumption in Ethiopia [5, 6].

Teff 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

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factors result up to 22% reduction in grain and straw yield [4]. Therefore, further improvement of product and productivity of tef is highly needed; as even improved varieties of teff are reported to yield only up to 2.2 t ha^{-1} on farmers' field [4] and the national average yield is about 1.76t ha^{-1} [8].

However, some improved technologies have been identified to stimulate teff production and productivity. The improved teff varieties have not been widely accepted, seemingly associated with low consumer demand for the better performing varieties [3]. 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 [10]. 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 [10]. 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 [11]. Tareke and Nigusse [12], Alemat *et al.* [13] recommended a row spacing of 20 cm, while Fekeremariam *et al.* [14] 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 [15]. Row planting in teff 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 [16, 17].

When the plant density exceeds up to the optimum level, competition among plants for light above ground and also for nutrients below the ground becomes severe. Consequently, plant growth suppressed down and the grain yield found in decreasing order [18, 19]. There was significant increase in yield components of teff with decreasing seed rate from highest to lowest. The lodging percentage of the crop was also reported increased by increasing the seed rate [20]. Abreham [21] reported that plant height was increased with decreasing seeding rates of teff. Plant height decreased as seeding rates increased. This could be because of high competition among teff plants for common resources such as nutrient, light, moisture and space at the highest density and this could hinder the development of plant height and panicle length [21]. Plant height highly significantly increased with decrease in the seed rate from the broadcast to 10 kg ha^{-1} due to the fact that there is enough space between teff crop which gave the highest plant height [11]. Tareke *et al*. [22] also indicated that, planting of teff in drilling method with lower seed rates resulted in taller plants.

Teff planting methods, such as broadcasting, row planting and transplanting, are also among the major factors which are responsible for limiting the teff production. Most of the farmers practicing the traditional method of sowing that is broad casting and generally for small sized seeds the seed rate requires about 25-30 kg ha^{-1} [12], which creates the excess crop density and also increases competition among the plants for up taking of nutrients, water, sunlight and CO_2. Moreover, broadcasting method of sowing requires additional and extra seed rate compared to the row sowing method and thus found increases in cost of production. Furthermore, it is also observed that broad casting sowing method resulting in to the more plant population which creates the lodging; which is the main cause for low yield in teff due to higher plant density [16, 17, 23]. Hence, it is necessary to determine the optimum density of plant population per unit area to obtain the maximum yield production [12]. The yield of transplanted and drilled has increased three to fourfold. The yield of the broadcasting plot was 500-1200 kg ha^{-1} whereas the transplanted and drilled one gave 3, 400-5, 100 kg ha^{-1} with three to fourfold increase in grain yield [24]. Grain yield highly significantly increased with decrease in the seed rate from the broadcast to 10 kg ha^{-1} due to the fact that teff tillers, as there is enough space. Application of 10 kg seed with 25 cm row spacing gave the highest plant height [11]. Tareke and Nigusse [12], Alemat *et al*. [13] recommended 20 cm row spacing.

In Kiltu Kara District the teff is cultivated as a major crop by the farmers among all the available crops in this particular area and observed potential area for the teff production. In the area farmers were traditionally practicing broadcasting method of sowing for teff cultivation and farmers are using high seed rate between 25 to 50 kg ha^{-1} with this method of sowing and there was not clear recommendation of row spacing to drill or transplant the teff seeds for different varieties. Hence, indeed need for knowing the optimum seed rate and row spacing of teff for the area. Therefore, the objective was to determine the effects of seed rate and row spacing on phenology, growth, yield and economic feasibility of teff in Kiltu Kara District of Western Ethiopia.

MATERIALS AND METHODS

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 distirct is located at 517 km away from Addis Ababa capital city of the country (Figure 1). It lies at the latitude of 9° 39'27" N and longitude of 35°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°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 [25].

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 were white in colour and small in size and reported more in production than the existing cultivars with little tolerance to the lodging.

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

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 a 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 1-2cm 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.

Collected Data

Days to 50% Emergence: Was counted from sowing up to the date when 50% of the seedlings were emerged in a plot after sowing with visual observation.

Days to 50% Heading: Was counted from sowing up to the date when the tips of the panicles were first emerged from the main shoot on 50% of the plant in a plot.

Days to 90% Maturity: Was visual counted in number of days from the date of sowing up to the date when 90% of the plants appeared in light yellow color and seems to drying.

Plant Height: Was randomly selected from the middle of the rows of entire plot and were measured from the base of the main stem to the tip of the panicle with measuring scale.

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}.

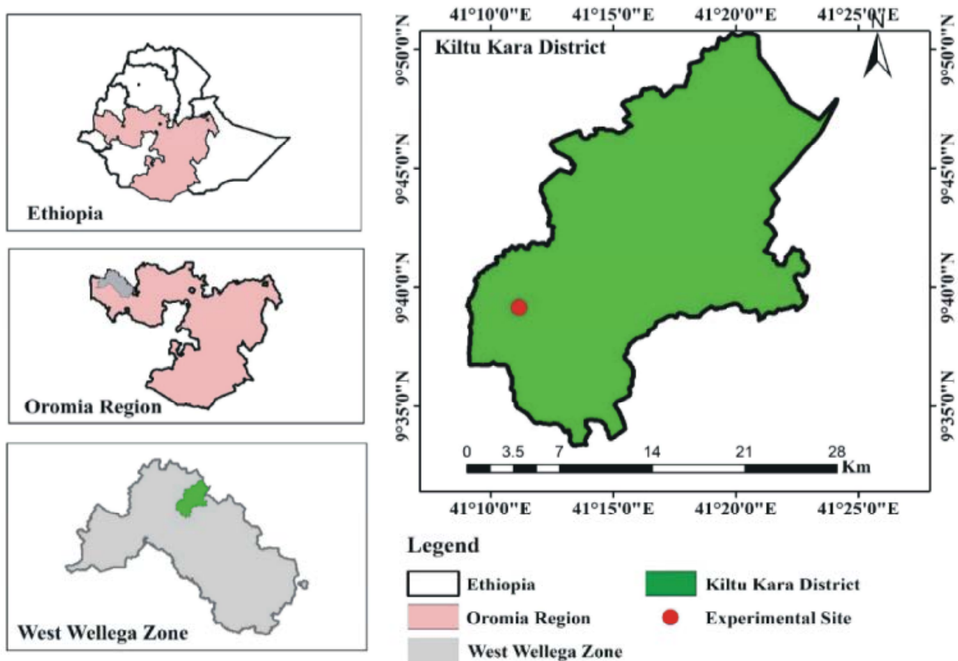

Fig. 1: Map of Study Area

Data Management and Analysis: All the data collected was subjected to the analysis of variance (ANOVA) using SAS software version 9.4 programs [26]. When ANOVA showed significant differences, mean separation was carried out using Least Significant difference) test at 5% level of significance [27]. 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.

Partial Budget Analysis: Partial budget analysis will be performed to evaluate the economic feasibility using different varieties. The partial budget analysis as described by CIMMYT [28] was used to determine the economic feasibility of seed rates. The average yield was adjusted downward by 10% to reflect the actual farmers practices [28]. The cost of improved seed of teff was 34.10 EB kg^{-1}. Average cost of grain price of teff was 3200 EB 100 kg $^{-1}$and straw price of teff was estimated to 7 EB kg^{-1}.

RESULTS AND DISCUSION

Days to 50% Emergency: The mean days to 50% emergency of teff was indicated in Table 17. There was non-significant variation on days to 50% emergence of teff due to the main effects of seed rate and row spacing and their interactions (P>0.05) (Table 1). The lack of significant effects of seed rate, row spacing and their interaction 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. This suggestion is consistent with that of Jan *et al.* [29] that embryo grows at the expense of stored food materials and did not require any external nutrition. In contrary, Tarekegne [30] reported that seed rate has direct effect on emergency and productivity of teff. Bekalu and Arega [31] found days to 50% crop emergence was significantly affected by seed rate and seeding of 10 kg ha^{-1} delay the days to emergency by one day as compared with other seed rates.

Days to 50% Heading: Days to 50% heading of teff was significantly (P<0.05)) affected by seed rate, row spacing and their interaction (Table 1 and 2). Mean days of 50 % heading of teff was decreased as seeding rate increased and the longer days to 50% heading of teff was recorded from 10 kg ha^{-1} of seeding rate. The use of 15cm row spacing was headed earlier as compared to wider row spacing of teff (Table 1). Mean days to 50% heading of teff heading (50) days were noted when 10 kg ha^{-1} seed rate was planted with 25cm row spacing was used, followed by 10 kg seed rate ha^{-1} and 20cm row spacing which takes (49) days to heading. While shortest days to heading (48) days were noted from plots in which 25 kg seed ha^{-1} was used with 15 cm row spacing (Table 2).

Table 1: Effects of seed rate and row spacing on days to 50% emergence, days to 50% heading and days to 90 % maturity of teff in Kiltu Kara district

Seed rate (kg ha^{-1})	Days to 50% emergence	Days to 50% heading	Days to 90 % maturity
10	4	50[a]	99[a]
15	4	49[b]	97[b]
20	4	49[b]	97[b]
25	4	49[b]	97[b]
Mean	4	49	98
LSD (5%)	NS	0.38	0.65
Rows pacing (cm)			
15	4	48[b]	97[b]
20	4	49[a]	98[a]
25	4	49[a]	98[a]
Mean	4	49	98
LSD (5%)	NS	0.33	0.57
CV (%)	8.4	0.79	0.69

Means followed by different letter(s) in a column and rows are significant at 5% level of Probability, NS= Non-Significant

Table 2: Interaction effect of seed rate and row spacing on days to 50% heading of teff in Kiltu Kara district

	Row spacing(cm)		
Seed Rate (kg ha^{-1})	15	20	25
10	49[cd]	49[ab]	50[a]
15	49[de]	49[cd]	49[bc]
20	48[ef]	49[dc]	49[dc]
25	48[f]	49[bc]	49[cd]
Mean		49.03	
LSD (5%)		0.65	
CV (%)		0.79	

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

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. Likewise, Adugna [32] found that seeding rates significantly influenced phenological parameter of teff. Similarly, Hoshikawa [33], 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. Also, Abreham [21]; Bekelu and Arega [31] who reported increased seeding rate hastened heading of teff. Likewise, Adugna [32] report indicated that, seeding rate 25 kg ha^{-1} significantly delayed heading by 3.6 days as compared to 2.5, 5 and 7.5 kg ha^{-1}.

Days to 90% 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 [34]. The mean days to 90% physiological maturity of teff was significantly ($P<0.05$) affected by row spacing, seed rate and their interaction (Table 1 and 3). Decreasing the seeding rate of teff was significantly prolonged days to 90 % maturity of the teff (Table 1). Teff planted 10 kg ha^{-1} seeding rate matured significantly later (99) days as compared to other seeding rates (15, 20 and 25 kg ha^{-1}) which takes (97) days (Table 1). Similarly, Sate and Tafese [35] reported that days to 90% physiological maturity of teff was significantly affected by main effects of seed rates and increase in days to 90% physiological maturity of teff with decreasing seed rate from 25 to 10 kg ha^{-1} might be due to use of growth resources.

Planting of teff 15 kg ha^{-1} seed rate with row spacing of 25 cm was mature with days to maturity (98) and similar with 20 kg ha^{-1} seed rate with row spacing of 20 cm and 25 kg ha^{-1} seed rate with row spacing of 20cm (Table 3). Thus, the maturity time of teff grown at the seeding rate of 10 kg ha^{-1} with row spacing of 25 cm was prolonged by about 3% compared to the maturity time of teff grown at the seeding rate of 25 kg ha^{-1} with row spacing of 15 cm. Corroborating, plants grown at low seeding rates had prolonged maturity time whereas those grown at higher seeding rates had hastened maturity [36]. He further 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, 20 and 15 kg ha^{-1} brought about early maturity of the teff crops than that of 10 kg ha^{-1}. 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. Plants grown at the seeding rates of 10 kg ha^{-1} conditions took the longest time to achieve physiological maturity in this study. Also, Sewenet [37] reported that cereals grown under adequate growth factors and space, delayed their

Table 3: Interaction effect of seed rate and row spacing on days to 90% maturity of teff in Kiltu Kara district

	Row spacing (cm)		
Seed rate (kg ha^{-1})	15	20	25
10	98^{a}	99^{a}	99^{a}
15	97^{b}	97^{b}	98^{a}
20	97^{b}	98^{a}	97^{b}
25	96^{b}	98^{a}	97^{b}
Mean		97.58	
LSD (5%)		1.13	
CV (%)		0.69	

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

90% physiological maturity compared to those under competition for space and other growth factors. Similarly, Abreham [21]; Bekelu and Arega [31] who reported increased seeding rate hastened maturity of teff. Likewise, Adugna [32] report indicated that, seeding rate 25 kg ha^{-1} significantly delayed maturity by 2 days as compared to 2.5, 5 and 7.5 kg ha^{-1}.

The interaction effect of seed rate and row spacing was significantly (P<0.05) affect days to 90% maturity of teff (Table 3). The mean days to 90% maturity (99) days were noted when 10kg ha^{-1} seed rate and 25cm row spacing was used, as par with 10 kg seed rate ha^{-1} and 20cm row spacing which takes (99) days to maturity. While shortest days to 90 % maturity (96) days were noted from plots in which 25 kg seed ha^{-1} was used by 15cm row spacing (Table 3). Similarly, Refissa [38] found lower seed rate sown in rows took longer time to reach at their physiological maturity. This might be due to less intra-specific competition of plants resulted from reduced seed rate and better management of plants in the rows that contributed to fair utilization of growth resources in the soil.

Plant Height: The mean plant height of the teff is mainly controlled by the genetic makeup of a genotype and it can also be affected by the environmental factors [39]. Plant height is an important component which helps in the determination of growth [40]. The analysis of variance of the plant height of teff was significantly (P<0.05) affected by row spacing, seed rate and by their interaction (Table 4). Higher mean plant height (83) of teff with lower seed rate of 10 kg ha^{-1} and lower mean plant height (70) of teff with higher seed rate of 25 kg ha^{-1} was obtained (Table 4). This might be due to increasing seed rate per unit area, the inter competition for space, nutrient, moisture and sun light increases which results in shortest plant height. The taller plant height (80cm) of teff was recorded in wider row spacing of 25cm while the shorter plant heights (73cm) was recorded in 15 cm row spacing of teff (Table 4). This could mainly be attributed to larger seed rate resulting in higher competition for nutrients while in small seed rate less plant competition for nutrients [41]. This might be due to increasing seed rate per unit area, the inter competition for space, nutrient, moisture and sun light increases which results in shortest plant height. Similarly, Getahun *et al*. [11] reported that, plant height highly significantly increased with decrease in the seed rate from the broadcast to 10 kg ha^{-1} due to the fact that there are enough space between teff crop which gave the highest plant height. Likewise Tareke *et al*. [42]; Abreham [21] reported that plant height were increased with decreasing seeding rates of teff and decreased as seeding rates increased. This could be because of high competition among teff plants for common resources such as nutrient, light, moisture and space at the highest density and this could hinder the development of plant height.

The interaction of seed rate and row spacing was significantly (P<0.05) affected mean plant height of teff (Table 4). The taller mean plant heights (90cm) was obtained from the interaction effect of 10 kg seed rate ha^{-1} and 25cm row spacing of teff, followed by 10 kg seed rate ha^{-1} and 20cm row spacing which is (83cm) plant height. While shortest plant heights (69cm) were measured from the interaction effect of 25kg seed rate ha^{-1} was used with 15cm row spacing (Table 4). The mean plant height of teff was ranged from 69 to 90cm. The increase in plant height due to row spacing 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. Similarly, Getahun *et al*. [11] reported an increasing row space within the same seed rate showed a trend of increasing in plant height. Application of 10 kg seed with 25 cm row spacing gave the highest plant height. Also, Tareke *et al*. [22] planting of teff in drilling method with lower seed rates resulted in taller plants. Refissa [38] reported that increased plant height due to row sowing method and lower seed rate. Similarly, Sate and Tafese [35] reported that plant height was significantly affected by the main effects of seed rates and increase in plant height due to row sowing and 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 such as nutrients and soil moisture. In contrary, Gasim [43] reported that the plant height increased with increase in seed rate.

Table 4: Main and interaction effect of seed rate and row spacing on plant height of teff in Kiltu Kara district

	Row spacing (cm)			
Seed rate (kg ha^{-1})	15	20	25	Mean
10	76^{bcde}	83^{ab}	90^{a}	83^{a}
15	76^{bcde}	77^{bcde}	79^{bc}	77^{b}
20	71^{cde}	74^{bcde}	79^{bcd}	74b^{c}
25	69^{e}	70^{ed}	70^{cde}	70^{c}
Mean	73^{b}	76^{ab}	80^{a}	
	Seed rate	Row spacing	Seed rate X Row spacing	
LSD (5%)	5.4	4.75	9.5	
CV (%)	7.36			

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

	Row spacing (cm)			
Seed Rate (kg ha^{-1})	15	20	25	Mean
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

Grain Yield: Mean grain yield is the end result of many complex morphological and physiological processes occurring during the growth and development of crop [44]. The mean tillers, total biomass and thousand seed weight directly contributed for the grain yield [45]. 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), where, the use 10kg seed ha^{-1} produced the highest grain yields of teff (1123 kg ha^{-1}) followed by 15kg seed ha^{-1} which produced of (971 kg ha^{-1}) grain yields of teff. Higher seed rate (25 kg seed ha^{-1}) gave the lowest grain yields of teff (778 kg ha^{-1}) (Table 4). Significant increased mean grain yields of teff by decreasing the seed rate from 25 to 10 kg ha^{-1}. Likewise, Tareke *et al*. [42] 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, Abreham [21] found that lower seeding rates of teff gave the highest grain yield as compared to high seeding rates. Similarly, Delesa [45] also reported that low seeding rate increased grain yield due to increased yield components, which is in line with the present result. Likewise, Mitiku [20] 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, Bekalu and Arega [31] 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, Tareke *et al*. [22]; ATA [15] 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. Fanuel *et al.* [46] 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 Abraham *et al*. [47] reported in contrast to the yield components, decreasing the seed rate generally led to decreased grain yields. Abraham *et al*. [47] 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}. Likewise, contrary to the present findings, Sewunet [37] 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, Wubante *et al.* [19] 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 [48]. In contrary, Frizzell *et al.* [49] and Hussain *et al.* [50] shows 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 25cm (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, Shiferaw [41] 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, Getahun *et al*. [11] 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. Sate and Tafese [35] 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.

Effects of Seeding Rate on Economic Feasibility of Teff Production: Partial economic analysis was carried out to evaluate the economic performance of different seeding rates (Table 6). The highest net benefit EB 41437 ha^{-1} and value to cost ratio EB 81 per unit of investment was recorded from 10 kg ha^{-1} seed rate followed by 15 kg seed rate ha^{-1} with net benefit of EB 37337 ha^{-1} and value to cost ratio of EB 49 per unit of investment (Table 6). The lowest, net benefit EB 30167 ha^{-1} and value to cost ratio of EB 24 per unit of investment were recorded from 25 kg ha^{-1} seed rate (Table 6). The use of 10 kg ha^{-1} seed rate was economically feasible for teff production in the study area. Similarly, Dejene [51] reported that, teff sown at seed rate of 10 Kg ha^{-1} provides economically profitable for teff production. Likewise, Arega and Yemgnushal [52] also indicated that teff sown 5 kg ha^{-1} followed by 10 kg ha^{-1} is economically beneficial for farmers. Therefore, teff sown at 10 kg ha^{-1} is economically beneficial for farmers compared to the other treatments.

Table 6: Partial budget analysis of seed rate for teff production during 2019/2020 cropping season in Kiltu Kara district western Ethiopia

	Seed rate (kg ha^{-1})			
Items	10	15	20	25
Grain yield ((kg ha^{-1})	1123	971	887	778
Adjusted grain yield (kg ha^{-1})	1011	874	799	700
Straw yield (kg ha^{-1})	1371	1450	1414	1293
Field benefit of grain(EB ha^{-1})	32352	27952	25552	22392
Field benefit of straw (EB ha^{-1})	9596	10152	9901	9053
Total gross field benefit (EB ha^{-1})	41948	38104	35453	31445
Labour cost (EB ha^{-1})	170	255	340	425
Seed cost (EB ha^{-1})	341	512	682	853
TCV (EB ha^{-1})	511	767	1022	1278
Net benefit (EB ha^{-1})	41437	37337D	34431D	30167D
Value to cost ratio	81	49	34	24
MRR (%)				

EB= Ethiopian Birr, D= Dominated, Average cost of seeds 34.1 EB kg^{-1}, grain price of teff 3200 EB 100 kg $^{-1}$ and straw price of teff estimated to 7 EB kg^{-1}

CONCLUTION

Teff is a highly valued crop in the national diet of Ethiopians. Mean days to 50% heading, days to 90 % maturity, plant height and grain yields of teff were significantly improved with wider row spacing. The interaction of seed rate and row spacing was significant difference for days to heading, plant height, days to 90 % maturity and grain yields of teff. Significantly higher mean values of teff were found using 10kg seed rate ha^{-1} and 25cm row spacing. The highest net benefit EB 41437 ha^{-1} and value to cost ratio of EB 81 per unit of investment was recorded from use 10 kg ha^{-1} seed rate of teff. Proper row spacing and seed rates are the most important management factor affecting the agronomic characteristics of teff. The use of 10 kg seed rate ha^{-1} and 25cm row spacing was recommended for the teff production. Therefore, to give conclusive recommendation, further research over location and years should be undertake in Kiltu Kara District.

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