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Research Article

Boosting Tef (*Eragrostis tef* (Zucc.) Trotter)) Yield through the Use of Different Inter-Row Spacing and Seeding Rates

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Tef is the major staple cereal crop in Ethiopia. Broadcast method of sowing and lack of site-specific seeding rates are among the major constraints of tef productivity. In this context, a field experiment was conducted with the aim of optimizing inter-row spacing and seed rates for better growth and yield of tef in southern Ethiopia. Treatments consisted of five levels of seed rates (2.5, 5, 7.5, 10, and 12.5 kg ha^{-1}) and four inter-row spacing (15, 20, 25, and 30 cm) that were combined in factorial arrangement and laid out in a randomized complete block design with three replications. Phenology, growth, yield components, and yield data were collected. The results revealed that lodging, main panicle weight, biomass, and grain yield were significantly affected by the interaction effect of inter-row spacing and seed rates. Seed rate of 2.5 kg ha^{-1} at 20 cm inter-row spacing prolonged crop phonology, enhanced tiller formation, and increased panicle and 1,000-grain weight than other treatments. The maximum grain yield (2,400 kg ha^{-1}) was obtained from the combination 2.5 kg ha^{-1} seed rate with 20 cm inter-row spacing. Taking the agronomic and economic advantages, it was concluded that a seed rate of 2.5 kg ha^{-1} with an inter-row spacing of 20 cm was suggested for tef growing farmers with similar agroecology of the study area.

1. Introduction

Tef (*Eragrostis tef* (Zucc.)) Trotter is a cereal plant that belongs to the *Graminaceae* family. Tef can be grown anywhere in Ethiopia from sea level to 2,800 m above sea level (m.a.s.l), but it flourishes best at elevations of 1,800–2,100 m. a.s.l., with 750–850 mm of annual rainfall and temperatures of 10–27°C [1, 2]. Farmers give tef the highest priority since it performs better than other primary grains in difficult environmental conditions [3, 4].

Tef is one of the most important and prevalent cereal crops in Ethiopia, making up about 24.17% of all acreage and 17.12% of the nation's total grain production [5]. The national and regional averages of tef productivity were 1.76 and 1.48 t ha^{-1}, respectively, which is less than the attainable (1.8–2.8 t ha^{-1}) and potential yield (6 t ha^{-1}) [6]. Several constraints, including tef's susceptibility to lodging, poor soil fertility, broadcasting sowing method, late planting, inappropriate fertilizer administration, and seeding rate, can be blamed for the crop's low yield [7, 8].

Because tef has relatively tiny seeds, Ethiopian farmers are accustomed to distributing it at higher seeding rates of up to 35 kg ha^{-1} [8]. This tactic intensifies the struggle for resources and accommodation, which ultimately leads to low yield [9, 10]. In the meantime, earlier research data in the USA [11] showed that seed rates between 4.5 and 9.0 kg ha^{-1} led to improved tef growth and yield. Farmers in Wolaita Zone, South Ethiopia, advocated using a seed spreader to sow 10 kg ha^{-1} of tef per hectare [8].

Tef plants would reach their ideal population and maximum grain yield at a reduced seed rate if proper agronomic practices were employed. In order to boost tef yield in Ethiopia, there is an increasing interest in optimizing the seeding rate during row planting [12]. Furthermore, optimum seed rate and row planting of tef minimize the problem of lodging to a greater extent.

The crop's dry matter distribution, leaf photosynthetic capability, and plant architecture are altered by row planting [13, 14]. Tef seed yield is a function of population density, seed weight, and the quantity of tillers and panicles [15].

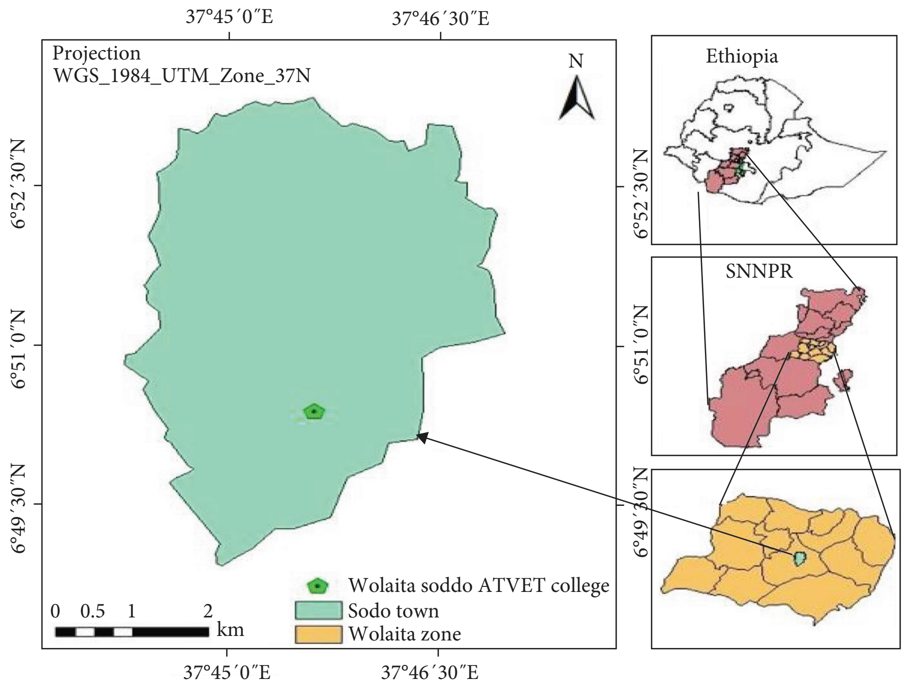

Figure 1: Map of the study area.

Hence, it is vital to generate location-specific information regarding the ideal seed rate and an inter-row spacing for the establishment of a homogeneous tef stand and high grain yield.

The recommended national tef seed rate for broadcast sowing is 25–30 kg ha^{-1}. By using a seed spreader and the broadcast approach, this seed rate was decreased to 10 kg ha^{-1} in the current study area [8]. Recently, there has been an interest in using row planting of tef across the country without a clear optimum seed rate for row planting [10, 12]. However, there have been attempts to determine the tef seed rate for row planting using rates ranging from 5 to 15 kg ha^{-1}. It was also reported that 5 kg ha^{-1} is the best seed rate for tef production using row planting. However, this recommendation missed the combined effect of seed rate with row spacing. Thus, the purpose of this study was to determine the interaction effect of row spacing and seed rate on tef phenology, growth, yield components, and yield.

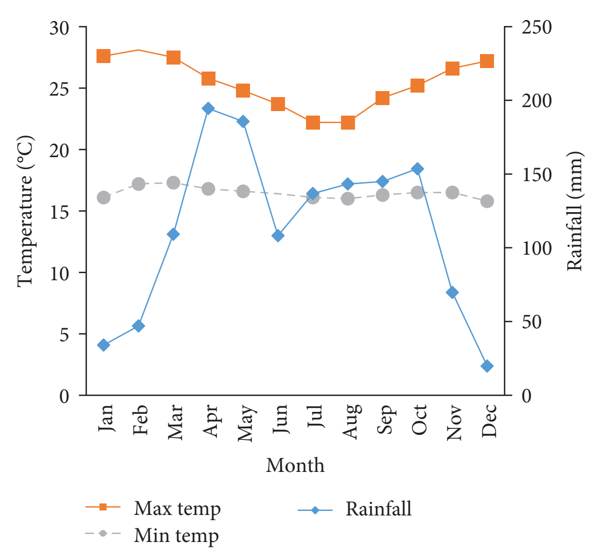

Figure 2: Monthly rainfall, maximum and minimum temperature of Wolaita Sodo Agricultural Technical Vocational Education and Training College in 2016.

2. Materials and Methods

2.1. Description of the Experimental Site. The Wolaita Sodo Agricultural Technical Vocational Education and Training (ATVET) College demonstration field in southern Ethiopia served as the experiment site during the main cropping season (June to September) in 2016 (Figure 1). An approximate geographical coordinate of the area is 6°34′N latitude and 37°43′E longitude having an altitude of 1,883 m.a.s.l. The area is characterized by a bimodal rainfall distribution pattern, with the total rainfall in the cropping season being 480.8 mm, and the mean maximum and minimum temperatures were 24.91 and 15.35°C, respectively (Figure 2).

2.2. Treatments and Experimental Design. Four inter-row spacings (15, 20, 25, and 30 cm) and five tef seed rates (2.5, 5, 7.5, 10, and 12.5 kg ha^{-1}) made up the treatments. In a randomized complete block design with three replications, the treatments were grouped in a factorial configuration (Table 1). Spacing of 1 and 0.5 m were maintained between consecutive blocks and plots, respectively. The gross and net plot sizes 4.8 m^2 (2 m × 2.4 m) and 1 m^2 (1 m × 1 m), respectively. One block (replication) had an area of 118.8 m^2 (49.5 m × 2.4 m).

Table 1: Layout of the field experiment consisting of seed rates and inter-row spacing.

Replication 1	Replication 2	Replication 3
S3R4	S3R4	S1R4
S4R2	S2R1	S4R1
S5R2	S2R4	S5R4
S5R1	S1R3	S3R1
S3R3	S1R2	S4R3
S4R4	S1R4	S1R2
S1R1	S3R1	S2R3
S2R2	S3R2	S1R3
S4R3	S3R3	S4R2
S1R4	S5R2	S3R4
S2R4	S4R1	S1R1
S5R4	S4R3	S2R2
S3R2	S5R1	S5R3
S3R1	S1R1	S5R1
S4R1	S2R3	S4R4
S1R3	S4R4	S2R4
S2R1	S4R2	S3R2
S5R3	S2R2	S5R2
S1R2	S5R4	S2R1
S2R3	S5R3	S3R3

S is for seed rate and R is for inter-row spacing, S1 = 2.5 kg ha^{-1}, S2 = 5 kg ha^{-1}, S3 = 7.5 kg ha^{-1}, S4 = 10 kg ha^{-1}, S5 = 12.5 kg ha^{-1}, R1 = 15 kg ha^{-1} cm, R2 = 20 cm, R3 = 25 cm, and R4 = 30 cm.

2.3. Description of Experimental Material. Tef variety Tsedey (DZ-Cr-37) was used as a test crop. The variety was developed and released by Debrzeit Agricultural Research Center in 1984. It is a high-yielding white-seeded with medium height and early mature cultivar with days to maturity of 82–90. The variety adapts to an altitude of 1,500–2,200 m.a.s.l and 150–200 mm annual rainfall during the growing period with a suitable temperature range of 10–27°C [16]. The variety is widely cultivated in the study area. Before sowing, seeds were mixed with fine dry soil (1 : 5) collected from the experimental site that passed a 2 mm diameter sieve. The sowing of seeds was carried out by drilling in the rows.

2.4. Experimental Procedures. The experimental field was plowed with an oxen plow four times prior to seeding. After plowing, the experimental field was leveled and pulverized into a smooth seedbed. Important agronomic techniques were implemented in accordance with the recommendation [17, 18]. Nitrogen (N) at 41 kg ha^{-1} and phosphorous (P) at 46 kg P_2O_5 ha^{-1} in the form of urea (46-0-0) and Di-ammonium phosphate (18-46-0) were applied. Phosphorous was administered during sowing, whereas N was applied twice (at the sowing and tillering stages). Following the local farmers' planting season, planting took place during the main cropping season.

2.5. Data Collection

2.5.1. Crop Phenology. Days to heading (days) are the number of days counted from seedling emergence until 50% of the plants in the plot produce a bloom or head. Days to physiological maturity (days) are calculated as the number of days from the time the first seedlings emerged until 90% of the plants in the plot reached the stage of phonological maturity.

2.5.2. Growth and Yield. Growth parameters were measured from ten randomly selected plants from a plot that were tagged prior to tillering. Plant height (cm) was measured as the distance from the base of the stem of the main tiller to the tip of the panicle at maturity. Panicle length (cm) was measured from the distance between the node where the initial panicle emerges and the tip of the main panicle when it reaches maturity. The main panicle weight (g) is the average weight of the main panicle at harvest from ten randomly chosen plants. The panicle number per plant was calculated by counting it from 10 randomly selected plants per plot at physiological maturity. Total dry biomass (kg ha^{-1}) was measured by weighing of all tef biomass from six central rows of each plot area after sun drying for 2 or 3 days. Grain yield (kg ha^{-1}) was calculated by weighing the threshed grains from six central rows of each plot and converting the result in kilograms per hectare after adjusting the grain moisture content to 12.5%. Thousand seeds weight (g) were weighted from thousand seeds that were randomly selected from each plot and weighed using a sensitive balance and grain moisture content was corrected to 12.5% using a grain moisture tester.

2.6. Statistical Data Analysis. Using the statistical computing program SAS version 9.1.3 [19], an analysis of variance was performed on all of the gathered data. When there were discernible differences between the means of the treatments, the least significant difference (LSD) test was run at a 5% level of probability.

3. Results and Discussion

3.1. Days to Heading and Physiological Maturity. Days to 50% heading and days to 90% physiological maturity were significantly ($p < 0.05$) influenced by the main effects of an inter-row spacing and seed rate, respectively, but not by their interaction effects ($p > 0.05$) (Table 2). As inter-row spacing increased from 15 to 30 cm, days to heading and physiological maturity were delayed (Table 2). Plants grown at 15 cm of inter-row spacing took about 45 and 79 days to reach 50% heading and 90% physiological maturity, respectively. On the other hand, it took about 57 and 90 days to reach 50% heading and 90% physiological maturity, respectively, when they were grown at inter-row spacing of 30 cm.

Plants cultivated in close quarters may have reached 50% heading and 90% physiological maturity earlier because of resource competition, which drove them to change their phenology from the vegetative to the reproductive stage. On the other hand, plants grown with wider row spacing had more access to resources and took longer to mature. According to Gorgy [20], rice plants' days to 50% heading were speeded up by close row spacing, which is consistent

Table 2: Days to heading and physiological maturity as affected by the main effect of inter-row spacing and seed rate of tef variety (DZ-Cr-37).

Factors	Days to panicle emergence	Days to physiological maturity
Inter-row spacing (cm)		
15	45.10[d]	78.87[c]
20	54.87[c]	83.20[b]
25	55.60[b]	88.13[a]
30	56.87[a]	90.27[a]
LSD (0.05)	0.5	2.1
Seed rates (kg ha^{-1})		
2.5	56.10[a]	86.75[a]
5	53.20[b]	86.58[a]
7.5	52.60[c]	85.42[ab]
10	52.00[d]	83.92[bc]
12.5	51.41[d]	82.92[c]
LSD (0.05)	0.56	2.4
CV (%)	1.3	3.5

Means followed by the same letter within a column are not significantly different at a 5% probability level.

with this finding. Similarly, Mekonnen [21] found that narrower inter-row spacing allowed for shorter days to 90% rice maturity. Additionally, the closer inter-row spacing (20 cm) accelerated the physiological maturation of wheat [22]. The phonological stage of plants grown in close-cropped rows was shortened, and the plant developmental phase moved earlier, as a result of competition for assimilates when resources are depleted sooner [23].

As the seed rate increased from 2.5 to 12.5 kg ha^{-1}, the time required to obtain 50% panicle emergence and physiological maturity began to shorten (Table 2). Therefore, the longest (56.1) and shortest (51.41) days to 50% heading were observed at seed rates of 2.5–12.5 kg ha^{-1}, respectively. The same seed rates yielded the longest (86.75) and quickest (82.92) days to 90% physiological maturity.

The delay of these phenological phases at lower seeding rates may be due to less plant competition, whereas, at higher seeding rates, there is intense competition for securing growth resources, which stresses the plant and causes it to shift from its vegetative growth stage to its reproductive growth stage [24]. In agreement with this result Abdulkerim [25] confirmed that increasing the levels of seeding rate of wheat crops shortened the number of days to 50% heading. The current result was in line with the findings of Ameyu [26], who noted that a lower seed rate made tef plants to take a long time to reach their physiological maturity. Additionally, according to Lakew and Berhanu [27], the 90% physiological maturity of tef was shortened when the seed rate rose. In another area, larger tef density brought on by a higher seed rate caused plants to use the major growth resources more quickly by engaging in intra-specific competition, which in turn caused the crop to mature earlier [27].

3.2. Lodging Index. The main and interaction effects of inter-row spacing and seed rate had a significant ($p < 0.05$) effect on the lodging index of tef (Figure 3). The highest lodging index (65.08%) was obtained from tef planted at 15 cm row spacing and a seed rate of 10 kg ha^{-1}, while the lowest

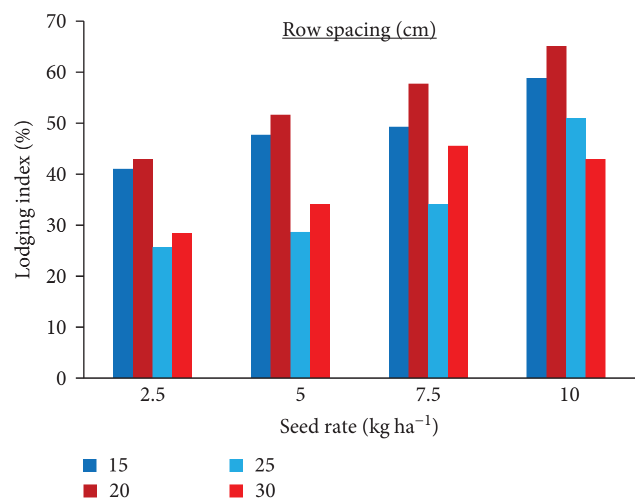

Figure 3: The interaction effect of row spacing and seed rate on lodging index (%) of DZ-Cr-37 tef variety.

lodging index (25.68%) was obtained from row spacing of 25 cm with a seed rate of 2.5 kg ha^{-1}. Taller plants with a weak and thin tef stem may exhibit greater lodging values with higher seed rates and tighter row spacing. The robust and sturdy stem of the tef plant, on the other hand, may be associated with a lower lodging index at a lower seed rate with wider row spacing because of less density stress.

This result is in agreement with the finding that tef's low plant density results in low lodging [28, 29]. A decreasing tendency of tef lodging was also reported by Ameyu [26], which resulted from row planting and less seed rate. A disorganized light profile is also linked to the propensity of plant lodging at higher seed rates, which results in taller and weaker plants that are more vulnerable to changing climatic conditions [30, 31]. Reduced lodging (%) is one way that a proper seed rate helps to increase tef output [32]. When the tef stem can sustain the weight of the loaded

Table 3: The main effect of row spacing and seed rate on plant height, number of total tillers, and effective tillers per plant in tef.

Factors	Plant height (cm)	Number of tillers per plant	Number of effective tiller per plant
Row spacing (cm)			
15	91.76[a]	4.88[c]	4.13[c]
20	88.36[b]	5.95[b]	4.81[b]
25	85.09[c]	7.31[a]	6.10[a]
30	81.89[d]	7.74[a]	6.24[a]
LSD (0.05)	2.22	0.60	0.42
Seed rates (kg ha^{-1})			
2.5	81.57[c]	8.37[a]	7.16[a]
5	84.18[b]	7.10[b]	5.83[b]
7.5	86.51[b]	6.20[c]	4.98[c]
10	89.8[a]	5.59[cd]	4.54[cd]
12.5	91.81[a]	5.13[d]	4.00[d]
LSD (0.05)	2.48	0.66	0.47
CV (%)	3.5	12.4	10.6

Means followed by the same letter within a column are not significantly different at a 5% probability level.

head of grain more effectively, the incidence of lodging is also shown to be reduced [15, 33].

3.3. Plant Height. The interaction effect of row spacing and seed rate showed a nonsignificant effect on plant height (Table 3). On the other hand, the main effects of the two factors were significant. Thus, the finding showed that wider inter-row spacing resulted in a decline of plant height with row spacing of 30 and 15 cm, produced the shortest (81.89 cm) and longest (91.76 cm) plant heights, respectively. The consequence of intense competition among plants as a result of increasing density, which causes them to stretch in quest of light, may explain why plant height increases with a 15 cm narrowing of row spacing. The opposite of this conclusion, according to Wato [34], tef plant height increased with increasing row spacing due to less nutrient competition at wider row spacing.

The increase in plant height with the narrowing of row spacing (15 cm) might be related to the effect of severe competition among plants because of higher density, which makes them elongated in search of light. In another report, plant height of tef increased with increasing of row spacing as a result of less competition for nutrients at wider row spacing [34]. The outcome of the current study may be attributable to the influence of competition for light rather than nutrients because crowding at close plant spacing (greater density) causes an increase in competition intensity for light and plant elongation [35].

Regarding the seed rate, plant height was increased with an increase in seeding rate from 2.5 to 12.5 kg ha^{-1}. Thus, the taller plant was observed from a seed rate of 12.5 kg ha^{-1}, while a seed rate of 2.5 kg ha^{-1} resulted in the shortest plant, which might be attributed to higher inter-plant competition in higher plant density for light, resulting in elongation of internodes. Greater seed rates result in denser plant growth, which reduces light penetration through the plant canopy and encourages plants to grow longer vertically to catch the restricted amount of light than plants with lower plant densities [36]. In agreement with the current findings, the formation of more secondary tillers in sparsely populated stands, which tend to be shorter in height than plants at higher density, is reflected in the reduction of tef plant height in response to reduced seed [9].

3.4. Yield Components and Yield

3.4.1. Number of Tillers per Plant. The main effect of seed rates and row spacing on the number of tillers per plant was significant ($p < 0.05$) but not their interaction (Table 3). As row spacing increases from 15 to 30 cm, the number of tillers per plant increases (Table 3). Row spacing of 15 and 30 cm resulted in the lowest (4.88) and highest (7.74) number of tillers per plant, respectively. Because plants have better access to space, nutrients, water, and light when they are less in number in a given area, and they can produce more tillers as a defense against having fewer plants. Reports showed that wider inter-row spacing may lead to the creation of more tillers [24]. According to Asargew et al. [37], the largest tiller number per plant was obtained with a wider row spacing (30 cm) than it was with the smallest (15, 20, and 25 cm) row spacing. There were more tillers per plant of tef as row space increased (lower density) [38].

The present study showed that there was a tendency for fewer tillers per plant as the seed rate increased from 2.5 to 12.5 kg ha^{-1} (Table 3). The highest (8.37) and lowest (5.13) number of tillers per plant was produced at a seed rate of 2.5 and 12.5 kg ha^{-1}, respectively. The decrease in tiller count as the seed rate increased might be related to interplant competition for growth resources, which reduces the plant's tillering potential. Similarly, studies revealed that tef seedlings with lower seeding rates had more tillers per plant [8, 39]. There was a considerable decline in the quantity of tillers per plant when the seed rate increased in tef [13].

3.4.2. Number of Effective Tillers per Plant. The main effect of seed rates and row spacing on the number of effective tillers per plant was significant ($p < 0.05$) but not their interaction

Table 4: The main effect of row spacing and seed rates on panicle length, panicle number, main panicle weight per plant, and thousand seed weight of tef.

Factors	Panicle length (cm)	Panicle (number plant^{-1})	Main panicle weight (g)	Thousand seed weight (g)
Inter-row spacing (cm)				
15	41.36^{a}	16.20^{c}	1.24^{d}	0.34^{b}
20	39.83^{a}	16.31^{bc}	1.30^{c}	0.35^{ab}
25	37.48^{b}	17.41^{ab}	1.43^{b}	0.36^{a}
30	36.85^{b}	18.24^{a}	1.48^{a}	0.35^{ab}
LSD	1.54	1.15	0.037	0.014
Seed rates (kg ha^{-1})				
2.5	37.07^{c}	19.74^{a}	1.49^{a}	0.37^{a}
5	37.62^{c}	18.07^{b}	1.40^{b}	0.36^{ab}
7.5	38.76^{bc}	16.50^{c}	1.34^{c}	0.34^{bc}
10	40.26^{ab}	15.94^{cd}	1.34^{c}	0.34^{bc}
12.5	40.7^{a}	14.95^{d}	1.27^{d}	0.32^{c}
LSD	1.72	1.29	0.042	0.015
CV (%)	5.4	9.13	3.7	5.3

Means followed by the same letter within a column are not significantly different at a 5% probability level.

(Table 3). The number of effective tillers per plant in tef tends to increase as inter-row spacing increases from 15 to 30 cm. The fewest effective tillers (4.13) were produced at 15 cm spacing, while at 30 cm inter-row spacing, a higher number of effective tillers (6.24) per plant was produced (Table 3). The appropriate positioning of the plants in the field allowed for more aeration, greater light interception, and more photosynthetic activity, which may be responsible for the larger number of effective tillers with wider row spacing. In agreement with this finding, Rajbhandari [40] observed that as each plant had access to more space and nutrients when planted farther apart, more productive tillers were generated, which had a discernible effect on the total number of tillers. When the inter-row spacing increases from 10 to 30 cm, the number of productive tillers increases significantly [41].

Moreover, the number of effective tillers tended to decrease with an increased seed rate in tef (Table 3). The maximum number of effective tillers per plant (7.16) was recorded at a seed rate of 2.5 kg ha^{-1}, while the minimum number of effective tillers per plant (4.00) was attained when plots were seeded with the highest seed rate (12.5 kg ha^{-1}). This might be due to spaced, plants adequately used more water, light, air, and nutrients, which led to a greater amount of photosynthetic activity and, ultimately, a higher number of effective tillers per plant. This result agrees with the finding of Laekemariam et al. [8], who indicated that lower seed rates of tef resulted in an increased number of tillers per plant.

3.4.3. Panicle Length. The main effect of seed rates and row spacing on panicle lengths was significant ($p < 0.05$) but not their interaction (Table 4). Panicle length showed a significantly increasing trend as row spacing increased from 15 to 30 cm (Table 4). The longest (41.36 cm) and the shortest (36.85 cm) panicle lengths were recorded from row spacing of 15 and 30 cm, respectively. The longest panicle length at narrow row spacing might be related to more number of plants per given area, which brings elongation of the panicle. A similar study result showed that an increased panicle length was observed at narrow spacing because of less tillering capacity and competition among plants [42].

The longest (40.70 cm) and shortest (37.07 cm) panicle lengths were recorded at 12.5 and 2.5 kg ha^{-1} seed rates, respectively (Table 4). The longest panicle length at a higher seed rate might be attributed to increased plant density that results in competition among plants for light and other resources, which in turn causes panicle length to elongate. Similarly, a report indicated that panicle length increased with increasing seed rate in tef [12].

3.4.4. Panicle Number Per Plant. The main effect of seed rates and row spacing on the number of panicles per plant was significant ($p < 0.05$) but not their interaction (Table 4). The number of panicles per plant was increased significantly as row spacing increased from 15 to 30 cm (Table 4). Inter-row spacing of 30 cm produced the highest number (18.24) of panicles per plant, while at the lowest inter-row spacing (15 cm) produced the least panicle number (16.20). The increased number of panicles at the wider spacing was attributed to more interception of sunlight for photosynthesis and resulted in the production of more assimilate for partitioning toward the development of more panicle numbers. This favors growth and contributes to having more panicles per plant [43]. Thus, the number of panicles per plant reduced as the seed rate increased (Table 4). Plants with seed rates of 12.5 and 2.5 kg ha^{-1} produced the lowest (14.95) and highest (19.74) number of panicles per plant, respectively. The increased number of panicles per plant might be due to the plants' increased utilization of nutrients and available space. According to Arefaine et al. [22], panicle numbers rose with decreasing seed rates, which is consistent with this finding.

3.4.5. Main Panicle Weight. The main panicle weight of tef was increased significantly ($p < 0.05$) as row spacing increased from 15 to 30 cm (Table 4). The maximum (1.48 g) and

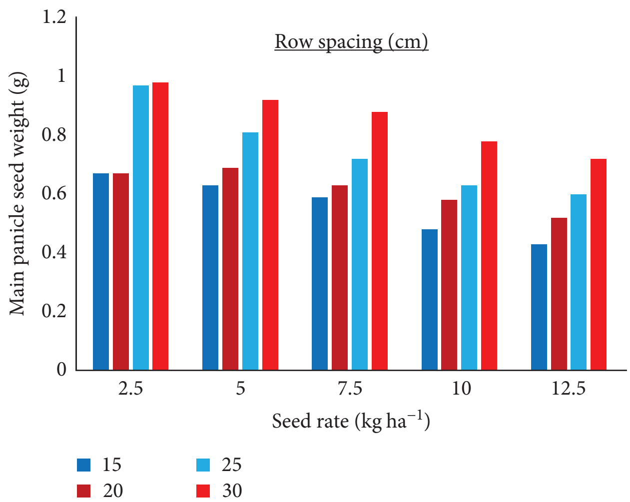

Figure 4: The interaction effect of row spacing and seed rate on seed weight of the main panicle in tef crop.

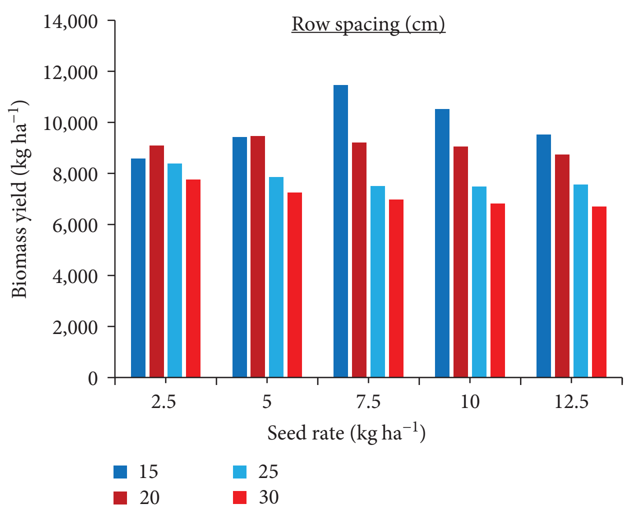

Figure 5: The interaction effect of row spacing and seed rates on biomass yield of tef crop.

minimum (1.24 g) main panicle weight per plant were obtained from row spacing of 30 and 15 cm, respectively. This result might be explained by the more effective use of water, nutrients, and light at wider spacing, as there is less inter-row competition and less plant population [44]. Likewise, Ali et al. [45] found that intense competition and close row spacing lowered the amount of photosynthate available during the growing period, which ultimately resulted in a decrease in grain weight and, consequently, spike (panicle) weight.

Overall, the panicle weight significantly increased with the decline in seed rate (Table 4). The maximum weight (1.49 g) was noted at a seed rate of 2.5 kg ha^{-1}, whereas the minimum value (1.27 g) was recorded at a seed rate of 12.5 kg ha^{-1}. The enhanced main panicle weight with decreasing seed rate might be due to the better utilization of growth resources among tef plants. The greater plant competition under a higher seed rate might have reduced assimilate synthesis, which in turn resulted in the lower main panicle weight of the tef. In line with this result, Reda [12] reported that lowering the seed rate of tef increased the main panicle weight.

3.4.6. Thousand Seed Weight. Row spacing and seed rate had a significant ($p \leq 0.05$) effect on thousand seed weights but not their interaction (Table 4). Thus, row spacing of 25 and 15 cm had the highest (0.36 g) and lowest (0.34 g) thousand-grain weights, respectively. A higher plant population was seen with narrower row spacing, which was accompanied by intense inter-row competition that reduced thousand seed weight [24]. In support of this finding, wider row spacing yielded more thousand seed weights in wheat than narrow row spacing did [45].

When the seed rate increased from 2.5 to 12.5 kg ha^{-1}, the weight of the thousand seeds decreased (Table 4). The highest (0.37) and lowest (0.32) thousand-grain weights were measured at seed rates of 2.5 and 12.5 kg ha^{-1}, respectively. At a low seed rate, there were fewer plants per unit area; plants were able to utilize more light and nutrients from the space that was available to each plant, leading to a maximum of a thousand seed weights at a reduced seed rate. The increasing thousand seed weight of tef with decreasing seed rate might be attributed to the effective exploitation of applied fertilizer [12, 46] and optimization of grain yield and crop quality [47].

3.4.7. Seed Weight of the Main Panicle. The seed weight of the main panicles was significantly ($p \leq 0.05$) impacted by the interaction effect of inter-row spacing and seed rates (Figure 4). Maximum panicle seed weight per plant (0.98 g) was obtained at 30 cm row spacing and a seed rate of 2.5 kg ha^{-1}. The lowest panicle seed weight per plant (0.43 g) was found at 15 cm row spacing and a seeding rate of 12.5 kg ha^{-1}. A better use of growth resources and the transfer of assimilates from source to sink (seed) might be the cause of the maximum panicle seed weight at a reduced seed rate and wider row spacing [45].

3.4.8. Biomass Yield. Biomass yield was significantly ($p \leq 0.05$) influenced by the interaction effects of inter-row spacing and seed rates (Figure 5). The highest biomass production (11,449 kg ha^{-1}) was attained with 7.5 kg ha^{-1} of seed rate and at 15 cm row spacing, while the lowest value (6,684 kg ha^{-1}) was attained with 12.5 kg ha^{-1} seed rate and at 30 cm row spacing. The greatest biomass yield was around 71.3% more than the minimum. The maximum biomass yield at the lowest seed rate and the narrowest row spacing suggests that as the distance between rows shrunk, the number of plants per unit area grew, leading to higher biomass yield and various yield components [48]. Biological yields rise with rising wheat populations up to a threshold, after which there is no further growth in yield [49]. Better performance of yield components and tillering per plant at wider row spacing and lower seed rate could not compensate for the yield losses of plants due to the reduced plant population

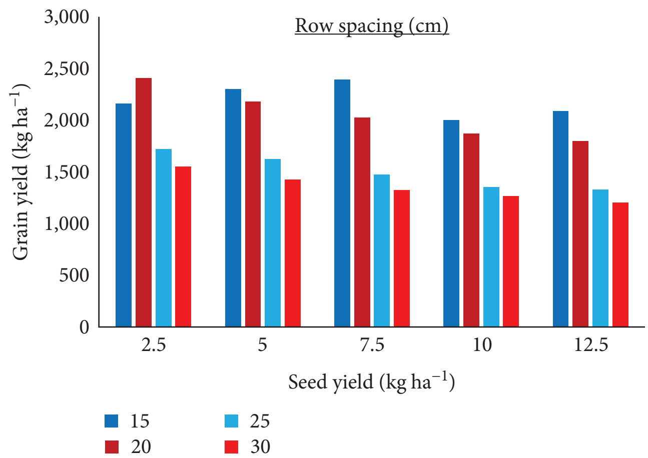

Figure 6: The interaction effect of row spacing and seed rate on grain yield of tef crop.

Table 5: The straw yield of tef (kg ha^{-1}) as affected by the interaction effects of row spacing and seed rates in tef crops.

Row spacing (cm)	Seed rates (kg ha^{-1})				
	2.5	5	7.5	10	12.5
15	6,424.8^{defg}	7,109^{bcd}	9,055.5^{a}	8,521.2^{a}	7,426.2^{b}
20	6,677.8^{cdef}	7,272.7^{bc}	7,188^{bc}	7,170^{bc}	6,942.6^{cbde}
25	6,664.5^{cdef}	6,221^{fgh}	6,026.5^{fghi}	6,120.6^{fghi}	6,233.1^{efgh}
30	6,212.9^{fgh}	5,816.3^{ghi}	5,644^{hi}	5,541.1^{hi}	5,480.8^{i}

Means followed by the same letter within a column within the same treatment category are not significantly different at a 5% level of significance. LSD (0.05) = 716.5, CV (%) = 6.5.

[50]; hence, plant numbers per a given area matter the biological yield [13].

3.4.9. Grain Yield. The grain yield of tef was significantly ($p \leq 0.05$) influenced by the interaction effects of the inter-row spacing and seed rates (Figure 6). Grain yield decreased as seed rate increased for all row spacings except 15 cm. Row spacing of 20 cm and a seed rate of 2.5 kg ha^{-1} resulted in the highest grain yield production (2,400 kg ha^{-1}). Row spacing of 30 cm and seed rate of 12.5 kg ha^{-1} resulted in the lowest grain production (1,200 kg ha^{-1}). The higher grain output might be due to the equal distribution of seeds and efficient use of the environment's resources. It is reported that row planting combined with a low seed rate resulted in the maximum grain yield of tef [51]. Furthermore, Laekemariam et al. [8] asserted that the grain yield was higher when tef was sown at the lowest seed rate (10 kg ha^{-1}), as opposed to when it was sown at the highest seed rates. Higher plant strength and yield were also attained at the proper seed rate and row spacing [22, 52]. A decreased seeding rate of tef also contributes favorably to an increase in grain output, according to Assefa et al. [2].

3.4.10. Straw. The straw yield was significantly ($p \leq 0.05$) impacted by the main and interaction effects of inter-row spacing and seed rates (Table 5). Increasing row spacing and seed rate resulted in a lower straw yield. The highest yield of straw (9,055.5 kg ha^{-1}) was recorded at a seed rate of 7.5 kg ha^{-1} with a row spacing of 15 cm, whereas the lowest yield of straw (5,480.8 kg ha^{-1}) was attained at a seed rate of 12.5 kg ha^{-1} with a row spacing of 30 cm. The large rise in tef straw yields with a reduction in row spacing may be attributable to a higher plant population per unit area. Straw yield followed the same trends as biological and grain yields, which were higher for tighter row spacing and lower seed rates. According to Bakht et al. [53] and Kalpana et al. [54], the highest straw yield on tef was seen on smaller spacings than on broader ones.

3.4.11. Harvest Index. The main effect of inter-row spacing and seed rate had a significant ($p < 0.05$) effect on the harvest index on tef variety; however, their interaction effect was not significant (Table 6). The lowest harvest index (19%) was obtained from the inter-row spacing of 30 cm, while the maximum harvest index (22.6%) was recorded at the inter-row spacing of 20 cm (Table 5). This might be a result of the higher grain production in the 20 cm inter-row spacing than in others. The highest harvest index was the outcome of higher grain yield [21].

With regard to seed rate, at the lowest seed rate (2.5 kg ha^{-1}), the maximum harvest index (23.04%) was observed, while the minimum harvest index (19.01%) was detected at the higher seed rate of 10 kg ha^{-1} (Table 6). The increased harvest index attained at the lowest sowing rate can be attributable to increased light penetration through the plant canopy. In contrast, the lowest value of HI (%) from a higher seed rate may

Table 6: The main effects of inter-row spacing and seed rate on harvest index of tef.

Treatments	Harvest index (%)
Row spacing (cm)	
15	22.4[a]
20	22.6[a]
25	19.3[b]
30	19[b]
LSD (0.05) = 1.06	
Seed rates (kg ha^{-1})	
2.5	23.04[a]
5	22[a]
7.5	20.4[b]
10	19.01[c]
12.5	19.5[bc]
LSD (0.05) = 1.2	CV (%) = 6.9

Means followed by the same letter within a column within the same treatment category are not significantly different at a 5% level of significance.

be due to increased competition for nutrients, light, and space. Similar to this, Zeng and Shannon [55] demonstrated that at high densities, the supply of carbohydrates was constrained by crop shading and competition between vegetative and reproductive growth. Similarly, it was stated that at an increased seed rate, the harvest index of tef values decreased [56–59].

4. Conclusion

Optimum intra-row spacing and seed rates would boost crop yield due to lower stress from competition among crop plants for available environmental resources. In the present study, it was recorded that lowering the tef seeding rate and widening inter-row spacing reduced lodging and also benefited the growth and yield of tef. Sowing of tef at 2.5 kg ha^{-1} seed rate and 20 cm inter-row spacing maximized the grain yield with a 100% yield advantage over the seed rate of 12.5 kg ha^{-1} with 30 cm inter-row spacing. From this result, it can be concluded that a seed rate of 2.5 kg ha^{-1} at 20 cm interspacing was the best combination to achieve maximum grain yield for the study site and other areas with similar agroecological conditions.

Data Availability

The authors declare that the data and materials presented in this manuscript can be made available on reasonable request.

Conflicts of Interest

The authors declare that they have no competing interests.

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References

[1] B. Haileselassie, T.-J. Stomph, and E. Hoffland, “Teff (*Eragrostis tef*) production constraints on Vertisols in Ethiopia: farmers’ perceptions and evaluation of low soil zinc as yield-limiting factor,” *Soil Science and Plant Nutrition*, vol. 57, no. 4, pp. 587–596, 2011.

[2] K. Assefa, J.-K. Yu, M. Zeid, G. Belay, H. Tefera, and M. E. Sorrells, “Breeding tef [*Eragrostis tef* (Zucc.) trotter]: conventional and molecular approaches,” *Plant Breeding*, vol. 130, no. 1, pp. 1–9, 2011.

[3] A. Reda, N. Dechassa, and K. Assefa, “Evaluation of seed rates and sowing methods on growth, yield and yield attributes of Tef [*Eragrostis tef* (Zucc.) Trotter] in Ada District, East Shewa, Ethiopia,” *American-Eurasian Journal of Agricultural & Environmental Science*, vol. 18, no. 1, pp. 34–49, 2018.

[4] A. A. Fikadu, T. D. Wedu, and E. A. Derseh, “Review on economics of tef in Ethiopia,” *Open Access Biostatistics & Bioinformatics*, vol. 2, no. 3, 2019.

[5] CSA (Central Statistical Agency), “Agricultural sample survey 2018/19 (2011 E.C.). Report on area and production of major crops (private peasant holdings, Meher season),” vol. 1, Central Statistical Agency, Addis Ababa, 2019, Statistical Bulletin, https://www.statsethiopia.gov.et/wp-content/uploads/2019/09/Report-on-Area-and-production-of-major-crops-2011-Meher-season.pdf.

[6] S. Ketema, *Phenotypic Variations in Tef (Eragrostis tef) Germplasm Morphological and Agronomic Traits. A catalog*, Institute of Agricultural Research, Addis Ababa, Ethiopia, Technical Manual No. 6, 1993.

[7] A. Reda, “Achieving food security in Ethiopia by promoting productivity of future world food tef: a review,” *Advances in Plants & Agriculture Research*, vol. 2, no. 2, pp. 86–95, 2015.

[8] F. Laekemariam, G. Gidago, and W. Taye, “Participatory seeding rates evaluation on teff (*Eragrostis teff* (Zucc.) Trotter) using seed spreader in Wolaita, South Ethiopia: farmers evaluation and economic analysis,” *Advances in Life Science and Technology*, vol. 5, pp. 37–42, 2012.

[9] G. Dereje, T. Adisu, and A. Dimberu, “Influence of seed rate and row spacing on growth and yield of tef (*Eragrostis* tef) production at Assosa, Benishangul-Gumuz regional state, Western Ethiopia,” *Advances in Crop Science and Technology*, vol. 6, no. 1, Article ID 335, 2018.

[10] J. B. Kumela and A. Thomas, “Performance of yield attributes, yield and economics of tef (*Eragrostis tef*) influenced by various row spacing, nitrogen and phosphorus fertilizers,” *African Journal of Plant Science*, vol. 10, no. 10, pp. 234–237, 2016.

[11] G. F. Stallknecht and K. M. Gilbertson, “Tef: food crop for humans and animals,” in *New Crops*, J. Jamick and J. E. Simon, Eds., pp. 231–234, Wiley, New York, 1993.

[12] A. Reda, “Evaluation of seed rates and sowing methods on growth, yield, and yield attributes of tef [*Eragrostis Tef (Zucc.)* Trotter] in Ada District, East Shewa, Ethiopia,” *Journal of Biology, Agriculture and Health Care*, vol. 4, no. 23, pp. 166–173, 2014.

[13] E. Aklilu, “Effect of seed rate and row spacing on yield and yield components of upland rice (*Oryza sativa* L.) in Metema, West Gondar, Ethiopia,” *American Journal of Agriculture and Forestry*, vol. 8, no. 4, pp. 112–125, 2020.

[14] A. W. Baloch, A. M. Soomro, M. A. Javed, M. Ahmad, H. R. Bughio, and M. S. Bughio, “Optimum plant density for high yield in rice (*Oryza sativa* L.),” *Asian Journal of Plant Sciences*, vol. 1, pp. 25–27, 2002.

[15] T. Berehe, *Report of New and Innovative Research Approaches to Increasing Productivity of Tef*, Sasakawa African Association, Addis Ababa, Ethiopia, 2010.

[16] Ministry of Agriculture and Rural Development (MoARD), *Crop Variety Register*, Animal and Plant Health Regulatory Directorate, Addis Ababa, Ethiopia, 2008.

[17] G. B. Tesfahunegn, "Short-term effects of tillage practices on soil properties under Tef [*Eragrostis tef* (Zucc. Trotter)] crop in northern Ethiopia," *Agricultural Water Management*, vol. 148, pp. 241–249, 2015.

[18] T. Tesfay and G. Gebresamuel, "Agronomic and economic evaluations of compound fertilizer applications under different planting methods and seed rates of tef [*Eragrostis tef* (Zucc.)Trotter] in northern Ethiopia," *Journal of Arid Land*, vol. 6, no. 1, pp. 409–422, 2016.

[19] S. A. S. (Statistical Analysis Software), *SAS/STAT User's Guide, Version 9.1.3*, SAS Institute Inc., Cary, NC, 2002.

[20] N. Gorgy, "Effect of transplanting spacing and nitrogen levels on growth, yield, and nitrogen use efficiency of some promising rice varieties," *Journal of Agricultural Research*, vol. 36, no. 2, pp. 123–146, 2010.

[21] A. Mekonnen, "Effects of seeding rate and row spacing on yield and yield components of bread wheat (*Triticum aestivum* L.) in Gozamin District, East Gojam Zone, Ethiopia," *Journal of Biology, Agriculture and Healthcare*, vol. 7, no. 4, pp. 19–37, 2017.

[22] A. Arefaine, D. Adhanom, and N. Tekeste, "Response of teff (Eragrostis tef (Zucc) Trotter) to Seeding rate and methods of sowing on yield and yield attributes in a subhumid environment, Northern Ethiopia," *International Journal of Agronomy*, vol. 2020, Article ID 1516790, 7 pages, 2020.

[23] A. A. Garba, B. A. Mahmoud, Y. Adamu, and U. Ibrahim, "Effect of variety, seed rate and row spacing on the growth and yield of rice in Bauchi, Nigeria," *African Journal of Food, Agriculture, Nutrition and Development*, vol. 13, no. 4, pp. 8155–8166, 2013.

[24] S. Sahle and T. Altaye, "Effects of sowing methods and seed rates on yield components and yield of tef in Soro Woreda, Hadya Zone, Southern Ethiopia," *Journal of Natural Sciences Research*, vol. 6, no. 19, pp. 109–114, 2016.

[25] A. Jemal, T. Tamado, and E. Firdissa, "Response of bread wheat (*Triticum aestivum* L.) varieties to seeding rates at Kulumsa, South Eastern Ethiopia," *Asian Journal of Plant Sciences*, vol. 14, no. 2, pp. 50–58, 2015.

[26] Y. Ameyu, *Influence of row spacing and nitrogen rates on yield and yield components of direct-sown irrigated rice at Gode, South-eastern Ethiopia*, M. S. Thesis, Haramaya University, Haramaya, Ethiopia, 2011.

[27] A. Lakew and T. Berhanu, "Determination of seeding rate and inter row spacing on the yield of tef (*Eragrostis tef* Zucc. Trotter) in the dryland areas of Wag Lasta, North Eastern Amhara, Ethiopia," *Archives of Agriculture and Environmental Science*, vol. 4, no. 1, pp. 69–74, 2019.

[28] K. Assefa, *Effects of some synthetic plant growth regulators on lodging and other agronomic and morphological characters of tef [Eragrostis tef (Zucc.) Trotter]*, M. S. Thesis, Alemaya University, Alemaya, Ethiopia, 1991.

[29] F. Hundra, T. Bogale, Assefa Tefera et al., "Agronomy research in tef," in *Narrowing the Rift: Tef Research and Development: Proceedings of the "International Workshop on Tef Genetics and Improvement"*, H. Tefera, G. Belay, and M. Sorrels, Eds., pp. 167–176, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia, 2001.

[30] D. Lemerle, B. Verbeek, and S. Diffey, "Influences of field pea (*Pisum sativum*) density on grain yield and competitiveness with annual ryegrass (*Lolium rigidum*) in south-eastern Australia," *Australian Journal of Experimental Agriculture*, vol. 46, no. 11, pp. 1465–1472.

[31] S. K. Khalil, A. Wahab, A. Rehman et al., "Density and planting date influence phonological development assimilate partitioning and dry matter production of faba bean," *Pakistan Journal of Botany*, vol. 42, no. 6, pp. 3831–3838, 2010.

[32] ATA (Agricultural Transformation Agency), "Innovations to help our country grow," 2012, http://www.ata.gov.et/programs/value-chain-programs/tef/.

[33] D. Assefa, B. Seyoum, and L. Oljira, "Determinants of multidrug-resistant tuberculosis in Addis Ababa, Ethiopia," *Infection and Drug Resistance*, vol. 10, pp. 209–213, 2017.

[34] T. Wato, "Effects of nitrogen fertilizer rate and inter-row spacing on yield and yield components of teff [*Eragrostis teff* (Zucc.) Trotter]," *International Journal of Plant & Soil Science*, vol. 31, no. 3, pp. 1–12, 2019.

[35] S. Xiao, S.-Y. Chen, L.-Q. Zhao, and G. Wang, "Density effects on plant height growth and inequality in sunflower populations," *Journal of Integrative Plant Biology*, vol. 48, no. 5, pp. 513–519, 2006.

[36] B. N. Otteson, M. Mergoum, J. K. Ransom, and B. Schatz, "Tiller contribution to spring wheat yield under varying seeding and nitrogen management," *Agronomy Journal*, vol. 100, no. 2, pp. 406–413, 2008.

[37] F. Asargew, Y. Bitew, M. Asfaw, M. Liben, and W. Getahun, "Row spacing and fertilizer rate on yield and yield components of tef [*Eragrostis Tef* (Zucc.)Trotter] under transplanting planting method," *Journal of Biology, Agriculture and Healthcare*, vol. 4, no. 15, pp. 133–136, 2014.

[38] W. Negash, A. Menzir, and M. Kassaye, "Effect of row spacing on yield and yield components of teff [*Eragrostis tef* (Zucc.) Trotter] varieties in Gonji Kolela district, North Western Ethiopia," *Journal of Biology, Agriculture and Healthcare*, vol. 7, no. 23, pp. 35–43, 2017.

[39] A. Giziew and B. Mebrate, "Determinants of the role of gender on adoption of row planting of tef [*Eragrostis tef* (Zucc.) Trotter] in central Ethiopia," *Ethiopian Journal of Science and Technology*, vol. 12, no. 1, 2019.

[40] R. Rajbhandari, *System of rice intensification under different plant populations and levels of Nitrogen*, M. S. thesis, Tribhuvan University, Rampur, Chitwan, Nepal, 2007.

[41] N. Hussain, A. Yasmeen, M. Arif, and H. Nawaz, "Exploring the role of row spacing in yield improvement of wheat cultivars," *Pakistan Journal of Agricultural Sciences*, vol. 51, no. 1, 2014.

[42] N. C. Brady and R. R. Weil, *The Nature and Properties of Soils*, Pearson Education Ltd., USA, 13th edition, 2002.

[43] B. Tulema, J. B. Aune, and T. A. Breland, "Availability of organic nutrient sources and their effects on yield and nutrient recovery of tef [*Eragrostis tef* (Zucc.) Trotter] and on soil properties," *Journal of Plant Nutrition and Soil Science*, vol. 170, no. 4, pp. 543–550, 2007.

[44] M. A. Sial, M. A. Arain, M. A. Javed, and N. A. Nizamani, "Response of wheat genotypes on yield and yield components with changing plant population densities," *Pakistan Journal of Botany*, vol. 33, pp. 797–800, 2001.

[45] M. Ali, L. Ali, M. Sattar, and M. A. Ali, "Improvement in wheat (*Triticum aestivum* L.) yield by manipulating seed rate and row spacing in Vehari zone," *Journal of Animal & Plant Sciences*, vol. 20, no. 4, pp. 225–230, 2010.

[46] M. Liben, A. Assefa, D. G. Tanner, and T. Tadesse, "The response of bread wheat to N and P application under improved drainage on Bichena Vertisols in North-Western Ethiopia," *Agronomy Journal*, vol. 94, pp. 1–6, 1991.

[47] A. Woyema, G. Bultosa, and A. Taa, "Effect of different nitrogen fertilizer rates on yield and yield related traits for seven durum wheat (*Triticum turgidum L. var* Durum) cultivars grown at Sinana, South Eastern Ethiopia," *African Journal of Food, Agriculture, Nutrition and Development*, vol. 12, no. 3, 2012.

[48] M. R. Smith, I. M. Rao, and A. Merchant, "Source-Sink relationships in crop plants and their influence on yield development and nutritional quality," *Frontiers in Plant Science*, vol. 9, Article ID 1889, 2018.

[49] N. P. Singh and R. A. Singh, *Scientific Crop Production*, Kalyani Publishers, Delhi, India, 1st edition, 2002.

[50] M. Hussain, M. Waqas-ul-Haq, S. Farooq, K. Jabran, and M. Farooq, "The impact of seed priming and row spacing on the productivity of different cultivars of irrigated wheat under early season drought," *Experimental Agriculture*, vol. 52, no. 3, pp. 477–490, 2016.

[51] S. Tolosa, *Effects of inorganic fertilizer types and sowing methods of variable seed rates on yield and yield components of tef [Eragrostis tef (Zucc.) Trotter] in Ada'a Woreda, Central Ethiopia*, M. S. Thesis, Haramaya University, Haramaya, Ethiopia, 2012.

[52] U. A. Soomro, M. U. Rahman, E. A. Odhano, S. Gul, and A. Q. Tareen, "Effects of sowing method and seed rate on growth and yield of wheat (*Triticum aestivum*)," *World Journal of Agricultural Sciences*, vol. 5, no. 2, pp. 159–162, 2009.

[53] J. Bakht, Z. Qamer, M. Shafi et al., "Response of different wheat varieties to various row spacing," *Sarhad Journal of Agriculture*, vol. 23, no. 4, pp. 839–845, 2007.

[54] A. Kalpana, P. Prusty, and S. K. Mukhopadhyay, "Performance of wheat genotypes under different row spacing in new Alluvial Zone of West Bengal," *Journal of Crop and Weed*, vol. 10, no. 2, pp. 480–483, 2014.

[55] L. Zeng and M. C. Shannon, "Effects of salinity on grain yield and yield components of rice at different seeding densities," *Agronomy Journal*, vol. 92, no. 3, pp. 418–423, 2000.

[56] Tafere Berhanu, "Effect of seeding rates and inter row spacing on yield, and yield components of bread wheat (*Triticum aestivum* L.) in dry land areas under selected districts of Wag Himra Zone, North Eastern Ethiopia," 2017.

[57] T. Wolde, *Teff in Southern Ethiopia. Effect of Seed Rates and Sowing Methods on Phenology, Growth, Yield and Yield Attributes at Wolaita Sodo*, GRIN Verlag, Munich, 2021.

[58] A. Takele, B. C. Nandeshwar, Z. Jalata, and K. Lamessa, "Response of tef (*Eragrostis tef* [Zucc.] Trotter) variety to varying seed rates and inter-row spacings for growth, yield and lodging severity in Western Ethiopia," *All Life*, vol. 16, no. 1, Article ID 222576.

[59] ATA (Agricultural Transformation Agency), "Annual Report: Transforming Agriculture in Ethiopia. Genetics and Improvement," Agricultural Transformation Agency, Addis Ababa, Ethiopia, 2014.