Optimizing Sowing Depth and Seeding Rate of Pelleted Seed for Reducing Lodging and Improving Yield of Tef

[1]Bizuwork Tafes, [1]Gebrekidan Feleke, [1]Almaz Meseret Gezahegn, [1]Sisay Eshetu, [1]Solomon Chanyalew, [1]Worku Kebede, [2]Zerihun Tadele, and [3]Dominik Klauser

[1]*Ethiopian Institute of Agricultural Research, Debre Zeit Agricultural Research Center, P.O. Box 32, Debre Zeit, Ethiopia;* [2]*University of Bern, Institute of Plant Sciences, Altenbergrain 21, CH-3013 Bern, Switzerland;* [3]*Syngenta Foundation for Sustainable Agriculture, Basel, Switzerland*

Abstract

The low productivity of tef is associated with problems inherent to tef botany and lodging. The small seed size of tef poses a major inheritance problem during sowing operations. Techniques such as pelleting seed with organic matter are effective to make them uniform in size and shape. A field study was conducted to determine optimum sowing depth and seed rate of pelleted tef for reducing lodging, and improving productivity of tef under Vertisol conditions during two consecutive cropping seasons (2019 and 2020). A factorial combination of four sowing depths (0, 1, 2 and 3 cm) and three pelleted tef seed rates (60, 90 and 120 kg/ha~5, 7.5 and 10 kg/ha of un-pelleted tef) were used as a treatment. The experiments were laid out in RCBD with three replications. Sowing depth had a significant effect on biomass and grain yield of tef. Tef sowing at the shallowest depth (0 cm) and 1 cm gave the highest biomass yield (11889 kg/ha and 9639 kg/ha, respectively) and grain yield (2786 kg/ha and 2536 kg/ha, *respectively). In contrast, the deepest sowing (3 cm) reduced biomass and grain yield of tef. Seed rate played an important role in the biomass yield of tef, the highest biomass yield (10399 kg/ha) was recorded from the 120 kg/ha seed rate of pelleted tef. Regarding lodging, the deepest sowing and lowest seed rate reduced lodging index and a number of root lodged plant. The average lodging index for the deepest sowing (3 cm) was 30.8%, while the shallowest (0 cm) was 69.3%. The result revealed that pelleted tef seed can successfully emerge from a depth of 1 cm without any apparent penalty of yield. Tef even emerged from 2 to 3 cm depth, while showing reduced lodging, but these had a yield penalty. Therefore, it can be concluded that a 1 cm sowing depth and 90 kg/ha pelleted tef are optimal for sowing pelleted tef seed for reducing lodging and improving yield.*

Keywords: Lodging, Pelleted seed, Sowing depth, Seed rate, Tef

Introduction

Ethiopia is the origin and center of diversity for many economically important crops including tef [*Egrostis tef* (Zucc.) Trotter], which belongs to the grass family and genus *Eragrostis* (Vavilov, 1951). Of the main cereal crops grown in the country, tef remains a crucial food crop interms of area coverage, production size, food and nutritional security as well as commercial value (Solomon *et al.*, 2019). Tef is a resilient crop that outperforms other cereals in terms of its husbandry and utilization efficiency (Minten *et al.*, 2018). Among the cereals grown in the country, tef is the first in terms of acreage, and the second most important cereal after maize in terms of grain production (CSA, 2020). The mean countrywide productivity of tef is about 1.8 tons/hectare, which is very low as compared to other crops such as wheat 2.9 tons/ha and maize 4.5 kg/ha tone (CSA, 2020). This low tef yield is seemingly explained by the limited knowledge about possible avenues for improving tef productivity, combined with problems inherent to tef botany (Habtegebrial *et al*., 2007; Berhe *et al*., 2011; Fufa *et al*., 2011).

The small size of tef seed poses problems during sowing and makes it difficult to control population density and its distribution. In addition, sowing depth and lodging of tef is a major cause in tef production (Seyfu, 1997). Tef is traditionally sown by manual seed broadcasting on wet soil and lightly covered with packed soil to prevent drying out (Ben-Zeev *et al*., 2018). For instant, shallow sowing depth would require avoiding seed desiccation in scattered rainfall or dry period. Ethiopian tef growers believed that tef seed will not emerge from 5 to 7 cm sowing depth (Bimro, 2016). However, under hot and dry soil conditions, deeper sowing of tef is recommended to guarantee seedling establishment (Kebede *et al*., 1986). As a general rule of thumb, seeds should not be sown deeper than five times their width (Paff and Asseng, 2018), as tef tiny seed size (0.4-0.7mm width and 1-1.4 mm length) thus maximum sowing depth is 2-3 mm. Elsewhere, the recommended sowing depth for tef is between 3 up to 15 mm (Andrea, 2008).

Plant lodging is defined as the permanent displacement of the stem from the vertical, which is caused by environmental conditions as well as morphological plant traits (Seyifu, 1983). It is the most significant yield-reducing problem in tef, accounting for up to 35% of yield losses (Van Delden *et al.,* 2010; Berry *et al.,* 2004). Certain studies relate tef lodging to stem characteristics (stem lodging) (Würschum *et al.,* 2017), while others (Van Delden *et al*., 2010 and Alemu and Tefera, 2019) pointed to shoot-root junction traits (root lodging) as major contributors to tef lodging. In cereal crops like wheat, deeper sowing has been shown to induce a longer, deeper root crown, thus improving plant anchorage and reducing root lodging and hence, reduced lodging could be an additional benefit of deeper sowing in tef (Pinthus, 1974; Ben-Zeev *et al*., 2020). The impact of seed rate on lodging was studied in various cereal crops. In wheat (*Triticum aestivum* L.), lower seed rate and direct drilling increased the size of the root plate, plant anchorage, and crown root length, thus reducing the risk or severity of lodging (2004). In rice (*Oryza sativa*), lower seed rates were associated with lower mutual shading, resulting in stronger stems, higher plant biomass, shorter basal internodes, and reduced lodging (Shah *et al*., 2019). In addition, maize (*Zea mays* L.), low plant densities led to shorter basal internodes, higher culm and root diameters, and more roots, resulting in less lodging (Xue *et al*., 2017). Very recently (Ben Zeev *et al.*, 2020), the study demonstrated for the first time, the feasibility of tef production under irrigated Mediter-ranean conditions and the potential of a reduced sowing rate as a remedy for lodging.

In seed technology, seed pelleting is a most useful technique for increasing the size of small seeds like tef, and coating them to make bigger, rounder, smoother, and more uniformly-sized seeds. The pelleting technique that can be adopted indirect sown small-seeded crops like sesame is seed pelleting, which modifies the microenvironment of the seed in favor of the seed (Alex *et al*., 2017). It is a coating technique that is used for handling of small-seeded crops and increases precision planting. It is not only increases the seed size but also reduces the seed rate, makes crop and seedling establishment uniformly and maintains the seed moist by making moisture available from the soil. However, to date, there has not been enough information regarding on pelleted tef seed for tef husbandry. Thus, keeping in view the above background and considering the importance of tef in the national economy, the study was designed to determine optimum sowing depth and seed rate of pelleted tef seed concerned on seedling emergence, growth and development, lodging, and productivity of tef.

Materials and Methods

Description of experimental site

The trial was conducted at Debre Zeit Agricultural Research Center research field for two consecutive cropping seasons (2019 and 2020) under rain-fed conditions. Debre Zeit Agricultural Research Center is located in East Shewa Zone of Oromia Regional State of Ethiopia. It is found 47 km away from South East of Addis Ababa, Ethiopia. Its geographical location is 8^{o} 44′ N latitude and 38^{o} 58′ E longitude. The altitude is about 1900 meters above sea level while, the majority of trial fields are heavy soils (*Vertisol*) with few pockets of light soil (Alfisols/Mollisols) (WRB, 2006). The rainfall pattern was well distributed in the 2019 and 2020 cropping months (June-October) with 678 mm, and 615 mm, respectively, at DZARC (Figure 1). Generally, rainfall received in the five months between planting to physiological maturity was optimum.

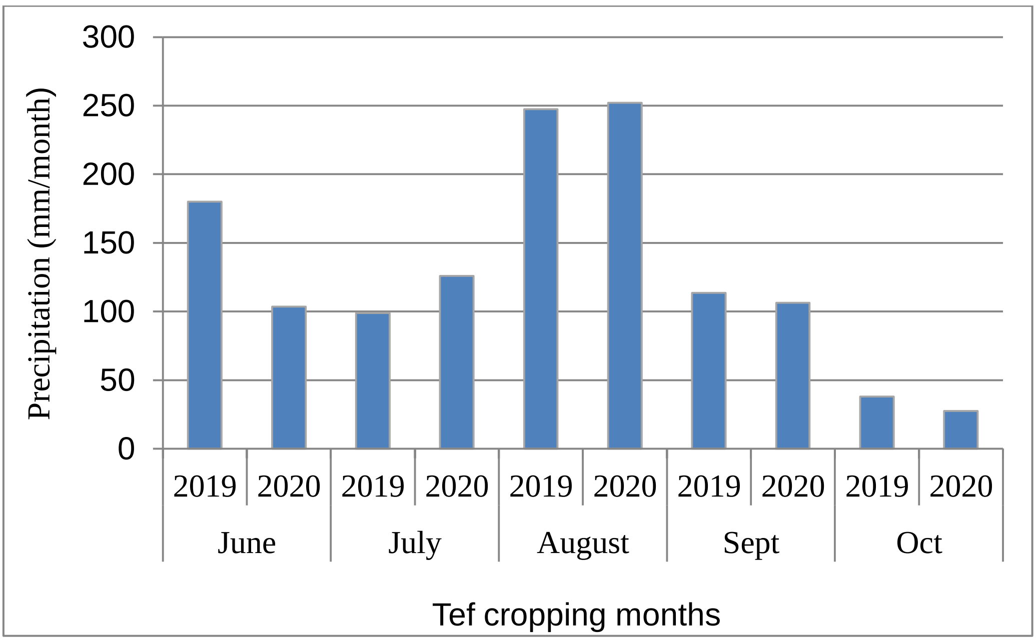


Figure 1. Rain fall distribution (mm) of during tef growing seasons (June to October) in 2019, and 2020 at DZARC.

Seed pelleting procedures

Pelleting process was done at Debre Zeit Agricultural Research Center (DZARC) in tef breeding laboratory room using a seed pelleting automatic machine (A-2000 Stockerau-Austria, Central CoATER type CCLAB). Tef variety, DZ-Cr-438 RIL91A (Dagme), which represent long maturity groups for the central highlands, was used as a test variety. The machine used in the pelleting process is composed of a convex stainless steel chamber, which has an adjustable and automated rotation speed. The pelleting technique consisted of 100 g of tef seeds, sawdust (wooden meal) 270 g, dry binder (donalim) 15 g and clay (pansil) 15 g followed by 100 g wet binder and 1140 g water were mixed in the plastic jar, intercalated with the coated materials, which were added until the pellets achieved the required diameter to be classified by a 2-2.4 mm round hole sieve. The binders, in the form of a powder, were mixed with the products along with water sprays during the pelleting process. Those seeds that did not reach a minimum required size, 2-2.4 mm, were returned to the machine to complete the pelleting process, the procedure was repeated until all the pellets reached minimum established the width of 2-2.4 mm.

Experimental design and field management

The experiment was laid out in Random Complete Block Design (RCBD) with a factorial arrangement using three seed rates (60, 90 and 120 kg/ha) of pelleted seed which are equivalent to (5, 7.5 and 10 kg/ha of un-pelleted tef seed), respectively, and four sowing depth [0 (control), 1, 2, and 3 cm]. Soil preparation included deep tilling and flattening with a heavy-duty leveler and crumble roller tool to obtain a smooth and even seedbed. A 2 m by 1.5 m plot size was used. Each treatment was replicated three times. A hole was made along in 20 cm row spacing using a hoe. To ensure an accurate sowing depth, the soil hole was measured by the ruler before planting then the seeds were sown using manually drilling and covered with a thin layer of soil.

Assessment of agronomic traits

Seedling emergence was recorded after 50% of seed emerged in each plot. Days to heading was scored as 50 % of the plant gave heading. Plant height was measured from the ground to the tip of tillers using a ruler and the mean value were determined in cm. Total tillers (both effective and non-effective) and productive tillers (effective tillers) were determined the crop reached physiological maturity by counting all the tillers from five randomly selected plants in each net plot and then calculating the mean value. Panicle length was measured in the field when the crop reached at physiological maturity. Five plants were randomly selected from each plot and measurements were made using a ruler from the bottom to the top of the panicle and calculated the average panicle length per plot. Aboveground biomass yield (AGBY): At maturity, the whole aboveground plant parts, including leaves, stems, and seeds from the net plot area in each plot were harvested, sun-dried and weighed and then expressed in kg ha^{-1}. Harvest index (HI) was calculated from the ratio of grain yield (GY) (GY at 12.5% grain moisture content to the above-ground biomass (AGB) (seed + straw) and it is expressed in percentage. Grain yield (GY): after harvesting, threshed grains were separated, cleaned the seed, and then after the grain were weighed by electronic balance. The GY was corrected to a moisture content of 12.5%, wet bases while a moisture tester was employed for measuring the moisture content.

Assessment of lodging traits

Lodging index: the degree of lodging was assessed just before the time of harvest by visual-observation based on the scales of 1-5 where, 1 (0-15°) indicates no lodging, 2 (15-30°) indicates 25% lodging, 3 (30-45) indicates 50% lodging, 4 (45-60°) indicates 75% lodging and 5 (60-90°) indicates 100% lodging (Donald, 2004). The scales were determined by the angle of inclination of the main stem from the vertical line to the base of the stem by visual observation. Each plot was divided based on the displacement of the aerial stem into all scales by visual observation. Then each scale was multiplied by the corresponding percentage given for each scale and the average of the scales represents a lodging percentage of that plot. Root lodging was assessed 10 days after physiological maturity. A metal frame with inner dimensions of 50 cm by 50 cm was placed across the crop in two spots per plot and the number of roots lodged plants within this frame area was counted and recorded.

Statistical analysis

Statistical analysis was conducted using SAS software and included a two-way analysis of variance. When significant treatment effects occurred, means separation were compared using LSD (0.05).

.

Results and Discussion

Days to seedling emergence and plant establishment

Days to seedling emergence in tef were significantly ($p \leq 0.05$) affected by the main effect of sowing depth (Table 1). Nevertheless, the main effect of the pelleted tef seed rate and the interaction of sowing depth with seed rate were nonsignificant. Days to seedling's emergence were delayed by 8.4 days from the shallowest sowing depth (0 cm) to 15.9 days at the deepest sowing (3 cm). However, there was nonsignificant difference in days required to germinate between 0 and 1 cm planting depth. Seedling emergence days were significantly delayed by 89% in the 3 cm sowing depth treatment as compared to 0 cm planting depth, but there was no significant difference from the seed planted at 2 cm sowing depth (Table 1). The delayed seedling emergence in deeper sowing (3cm depth) might be due to lower soil temperatures and took longer shoot grew result in delayed seedling emergence. According to Sharma *et al.* (2019), the seedling emergency has a direct impact on seed-to-soil contact as well as seeds' access to adequate moisture and temperature. Days of emergency were significantly delayed at the deepest sowing compared to the other shallow depths. Similar studies by Kirby (1993); Ben-Zeev *et al.*, (2020) found that, sowing tef at 1 or 2 cm depth has no or only minor effects on seedling emergence, however, sowing at 3 cm depth had a significant delay on this variable.

The days to heading were significantly affected by sowing depth but days to maturity, plant height and panicle length were not significantly affected by sowing depth (Table1). Similarly, the main effect of pelleting tef seed rate and the interaction effects of two factors were not significantly affected the above-mentioned traits. Days to heading was ranged from 58 to 61.5 days from 0 cm sowing depth and at 3 cm, respectively, and were generally prolonged days to heading as sowing depth increased (Table 1). This might be due to delayed seedling emergence in deeper sowing. Similar results were reported by Kirby (1993) and Ben-Zeev *et al.* (2020), sowing of tef in 3 cm depth was delay days to heading as compared to shallow sowing depth (0 cm).

Table1. Effects of pelleted tef seed rate and sowing depth on the seedling emergence and plant growth at DZARC over two years

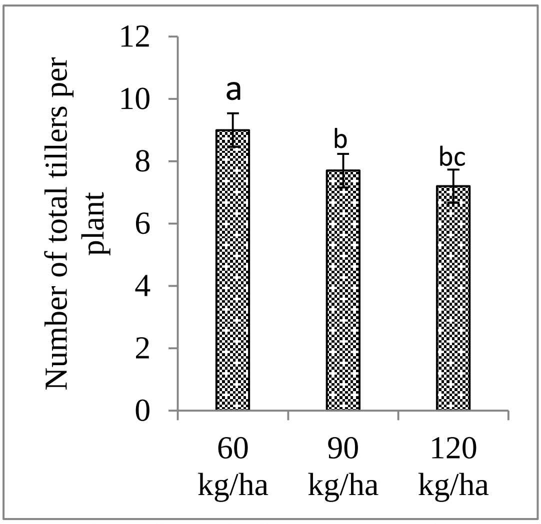
Treatments	DSE	DH	DM	PH (cm)	PL (cm)
Seed rate (kg/ha)					
60 pelleted ~ (5)	12.7	59.7	104.0	125.85	47.7
90 pelleted ~(7.5)	11.6	59.6	103.6	128.48	47.4
120 pelleted ~(10)	10.8	58.6	102.6	128.47	47.1
Sowing depth					
0 cm	8.4c	58.0b	101.9	130.18	48.5
1cm	10.2bc	58.8ab	102.9	128.13	47.9
2 cm	12.4ab	58.8ab	103.2	126.21	46.7
3 cm	15.9a	61.6a	105.6	125.88	46.5
CV (%)	2.1	6.2	8.3	6.5	6.6

DSE = days of seedling emergence; DH = days to heading; DM = days to maturity; PH = Plant height; PL= Panicle length; Means with the same letter in columns are not significantly different at 5% level of significance; CV (%) = coefficient of variation.

Total tillers and productive tillers

The main effects of pelleted seed rate and sowing depth had highly significantly affected the number of total tiller and productive tillers per plant. But the interaction effect of the two factors was not significant. The highest number of total tillers (9 plants) and productive tillers (6.7 plants) were obtained from the low pelleted seed rate (60 kg/ha) (Figures 1 and 2), respectively, but was not significantly different from the rate of 90 kg/ha. On the other hand, the lowest number of total tillers (7 tillers/plant) and productive tillers (5 tillers/plant) were produced at the highest pelleted seed rate (120 kg/ha) (Figure 1 and 2). The improvement in total and productive tillers at the lowest pelleted seed rate might be due to the low number of plants which were produced more number of tillers per plant. In contrast, sowing of higher seed rates of tef leads to competition among plants for nutrients, water, and sunlight, resulted in decreased tillers number per plant. More recently, studies by Alemu and Tefere (2019) and reported that tef cultivars sowing at a lower seed rate gave the highest tillers per plant.

Regarding to the sowing depth, the highest number of total tillers (9.5 tillers/plant) and productive tillers (6.9 tillers/plant) were obtained from the deepest sowing (3 cm), while the lowest number of total tillers (6.1 tillers/plant) and productive tillers (4.8 tillers/plant) were obtained in the shallowest sowing depth (0 cm) (Figure 3 and 4). The highest total tillers and productive tillers obtained from deep sowing might be due to in more deep sown had low seedling emergence, which resulted in low population density this lead that low plant population, the crop produced more tillers per plant. On the other hand, high seedling emergences were observed at a sowing depth of 0 and 1 cm it causes more population density reflected, low tillers numbers per plant. In contrast to these result, Kirby (1993) and Photiades and Hadjichris-todoulou (1984) found that a reduction in number of leaves and internode lengths, plant height and tiller number in deep sowing for wheat and barley. Similarly, Ben-Zeev *et al*. (2020) reported that sowing tef seeds at 3 cm depth significantly reduced tillers numbers.



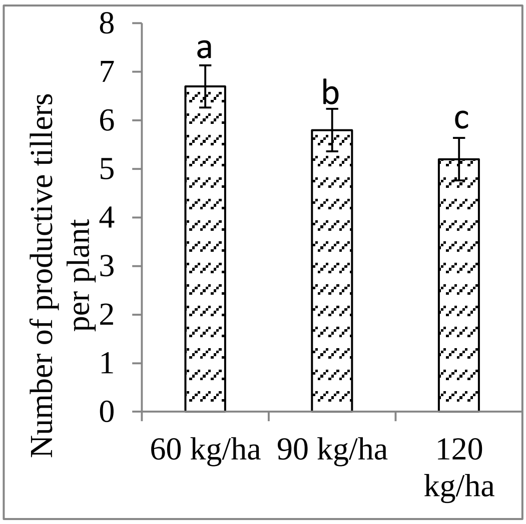


Figure 1& 2. Effects of different pelleted tef seed rate on the total tillers and productive tillers per plant on *Vertsol* conduction

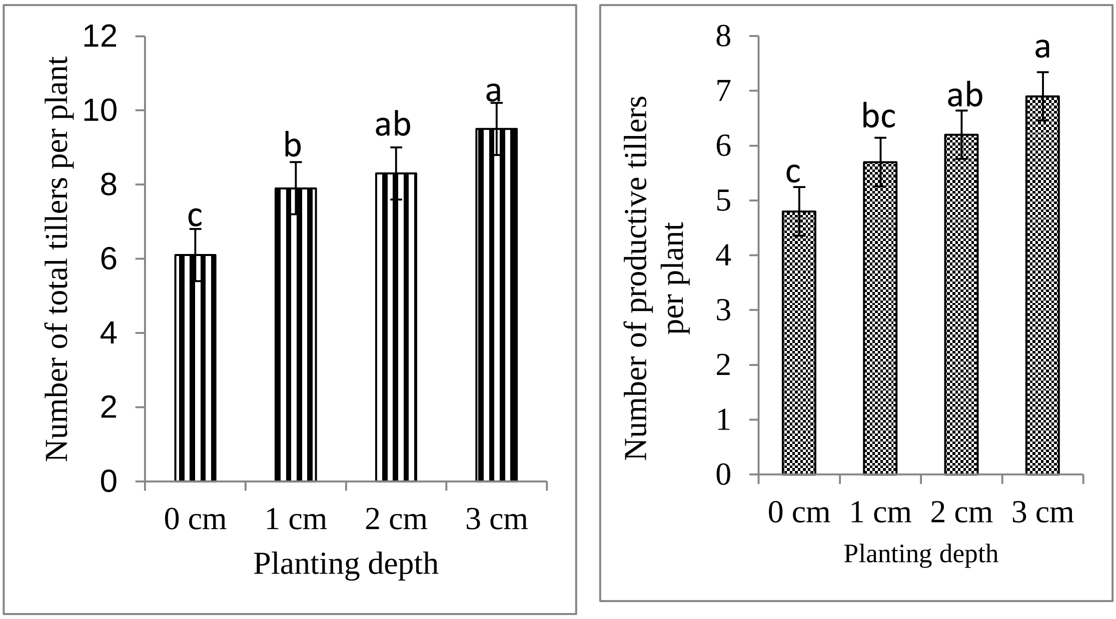


Figure 3 & 4. Effects of different sowing depth of tef seed on the total tillers and productive tillers per plant on Vertisol conduction

Biomass, grain yield and harvest index

Sowing depth had a significant effect on both biomass and grain yield while it had no significant effect on the harvest index. Interactions of sowing depth and pelleted tef seed rate were not significant (Table 2).

Sowing tef at 3cm depth significantly reduced biomass and grain yield as compared to shallow planting depth (0 cm). When compared to shallow sowing (0 cm) with a biomass yield of 11889 kg/ha and grain yield of 2785.9 kg/ha, deep sowing (3 cm) reduced biomass yields by 50% and grain yields by 39%. The negative effects of deep sowing on the biomass and grain yield were attributed to reduced plant establishment as a result reduced plants per meter square consequence reduce biomass and grain yield of tef. Similarly, plants sown at 3 cm depths grew in to shorter, developed lower plants per meter square and gave a lower grain yield than plants in the shallower sowing depth (Ben-Zeev *et al.*, 2020). Similarly, Kirby, (1993) and Photiades and Hadjichris-todo-ulou (1984) reported a reduction of biomass, and grain yield of wheat and barley, respectively in deeper sowing.

Regarding the seed rate, biomass yield was significantly affected by the pelleted tef seed rate (Table 2). Nevertheless, grain yield and harvest index were not significantly affected by the pelleted tef seed rate (Table2), suggesting compensation for the lower plant density by a number of tillers resulted in no significant difference achieved. The highest biomass yield (10399 kg/ha) was recorded from the 120 pelleted tef seed rate treatment, which was equivalent to 10 kg/ha un-pelleted tef seed rate. On the other hand, the lowest biomass yield was attended 60 kg/ha of pelleted seed rate of tef which was equivalent to 5 kg/ha of un-pelleted tef seed rate. Increasing the pelleted seed rate indicated significantly increases biomass yield of tef. There was a consistent increase in biomass yield with increasing pelleted tef seed rate. The highest biomass yield in the highest pelleted seed rate was probably the presence of maximum plants per meter square produced. The current result was strongly supported by Ben-Zeev *et al.* (2020).

Table2 . Effects of pelted tef seed rate and sowing depth on biomass yield, grain yield, and harvest index at DZARC over the two years

Treatments	AGBY (kg/ha)	GY (kg/ha)	HI (%)
Seed rate (kg/ha)			
60 pelleted ~ (5)	8878b	2295.2	0.27
90 pelleted ~(7.5)	9750ab	2455.0	0.26
120 pelleted ~(10)	10399a	2493.9	0.24
Sowing depth			
0 cm	11889a	2785.9a	0.24
1cm	9639b	2535.5ab	0.27
2 cm	9254bc	2333.3b	0.27
3 cm	7921c	2004.3c	0.25
CV (%)	18.3	17.9	25.0

AGBY=Aboveground biomass yield; GY= Grain yield; HI= Harvest index; Means with the same letter in columns are not significantly different at 5% level of significance; CV (%) = coefficient of variation.

Lodging index

Lodging index and root lodging were significantly affected by pelleted tef seed rate and sowing depth. However, the interaction effect of seed rate with sowing depth was not significant. The highest pelleted seed rate (120 kg/ha) had the highest lodging index value (56%) and the lowest pelleted seed rate (60 kg/ha) had the lowest lodging index (30%), while the intermediate seed rate (90 kg/ha) had intermediate lodging index values (44%), which did not significantly deferred from the highest and lower seed rates (Figure 5). In this finding, a low seed rate led to shorter basal internodes, higher culm and root diameters, and more roots, resulting in less lodging index. In sorghum (*Sorghum bicolor* L.), lower plant densities also led to stronger and thicker culms, which decreased the risk of lodging (Teetor *et al.*, 2017).

Regarding on the sowing depth, the average lodging index in 3 cm sowing depth was much lower (30.8%) than from the shallow sowing depth (0 cm) (69.3%) (Figure 6). Moreover, sowing depth has been shown significantly reduce root lodging in tef. The deepest sowing has been shown the lower number of root lodging of tef as compared to the shallowest sowing depth (Figure 7). Sowing of pelleted tef seed at 3 cm depth significantly reduced the average lodging index and root lodging compared to 0 and 1 cm sowing depth. This was possibly due to the formation of a deeper root length (Jabesa and Abraham, 2017) which improves plant anchoring to the soil. Recent report showed that deeper sowing of tef (Ben-Zeev *et al.* 2020; Würschum, 2017; Getahun *et al.*, 2018) and other cereals (Jabesa and Abraham, 2017) have been reflected an association between deeper sowing with reduced root lodging.

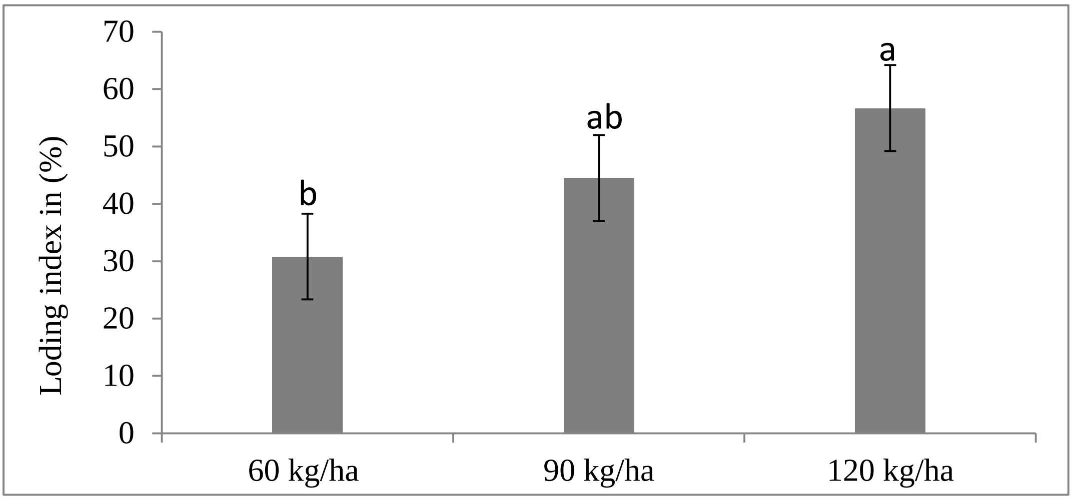


Figure 5. Effects of different pelleted tef seed rate on the lodging index of tef on vertisol

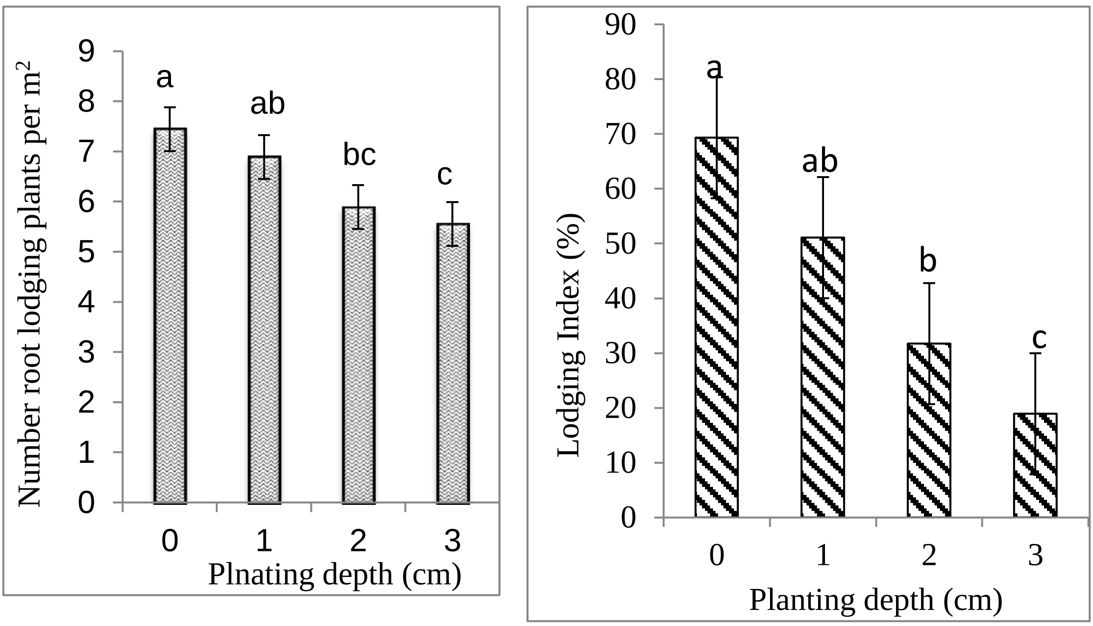


Figure 6 &7. Effects of different sowing depth on the lodging index and number of root lodging of tef on *Vertisol*

Figure 8. Root lodging (left) and stem lodging (right) in tef grown in field plots. Photo credited to Bizuwork Tafes.

Figure 9. Stand establishment of pelleted tef seed grown at DZARC. Photo credited to Bizuwork Tafes.

Conclusion

Based on the result, sowing depth and pelleted tef seed rate had a significant effect on yield, yield components and lodging index of tef. Pelleted tef seed successfully emerged from a depth of 1 to 2 cm without any apparent penalty of yield. Tef even emerged from 3 cm depth and reduced lodging, while showing reduced lodging, but this had a penalty of grain yield and biomass yield. The use of tef seed at a rate of 90 kg/ha produced better biomass, grain yield and reduced lodging index. Therefore, sowing of pelleted tef seed in 1 to 2 cm depth with 90 kg/ha seed rate should be recommended for produced highest tef grain yield. Future research should take combining different pelleted materials and sowing depth with different soil moisture levels, seed rate, soil type and lodging to increases tef productivity.

Acknowledgments

For this work, experimental site allocated and budget facilitated by Debre Zeit Agricultural Research Center and budget was supported by Syngenta foundation project. Pelleted tef seed was supported by National Tef Breeding Program at DZARC and experimental data collection were supported by the Agronomy and Crop Physiology Research Program staff at DZARC.

References

Alemu Lakew and Tafere Berhanu. 2019. 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*, 4(1): 69-74.

Andrea, T., Barnea, E. and Eisen, M.S. 2008. Organoactinides promote the tishchenko reaction: The Myth of Inactive Actinide Alkoxo complexe. *Journal of the American ChemicalSociety*, 130 (8), pp.2454 -2455.

Ben-Zeev, S., Bimro, J., Barak, V., Saranga, Y. 2018. Phenotypic diversity and heritability in Eragrostis tef under irrigated Mediterranean conditions. *Isr. J. Plant Sci.*, 65, 222-231.

Ben-Zeev S., Shane Kerzner, Onn Rabinovitz and Yehoshua Saranga. 2020. Optimizing Sowing Depth of Tef for Irrigated Mediterranean Conditions: From Laboratory to Field Studies. *Agronomy*, 1983; doi: 10. 3390/10121983.

Berhe, T., Gebretsadik, Z., Edwards, S., Areya, H. 2013. Boosting teff productivity using improved agronomic practices and appropriate fertilizer. *In*: Assefa, H; Chanyalew, S., Tadele, Z., (*eds*). Achievements and prospects of tef improvement. Ethiopian Institute of Agricultural Research and University of Bern, Institute of Plant Sciences. pp. 133-140.

Berry, P.M., Sterling, M., Spink, J.H., Baker, C.J., Sylvester-Bradley, R., Mooney, S.J., Tams, A.R., Ennos, A.R. 2004. Understanding and Reducing Lodging in Cereals. *Advanced Agronomy;* 84, 217-271.

Bimro, J. 2016. Agronomic Aspects of Tef (*Eragrostis tef*) Cultivation in Israel; The Hebrew University of Jerusalem: Rehovot, Israel.

Caldicott, J.J.B. Nuttall, A.M. 1979. A method for the assessment of lodging in cereal crops. *J. Natl. Inst. Agric. Bot.* 15, 88-91.

CSA (Central Statistical Agency). 2020. Agricultural sample survey 2019/2020 agricultural sample survey.

Fufa Hundera, Tesfa Bogale, Hailu Tefera, Kebebew Assefa, Tiruneh Kefyalew, Aberra Debelo and Seyfu Ketema. 2000. Agronomy Research in Tef. (*Eds*.) by Hailu Tefera, Getachew Belay, Mark sorrels. *Narrowing the rift tef research and development Proceedings of the "International workshop on Tef Genetics and Improvement*" Debre zeit, Ethiopia. 16-19 October, 2000.

Getahun Dereje, Tigist Adisu, Adisu Dimberu, 2018. Influence of Seed Rate and Row Spacing on Growth and Yield of Tef (*Eragrostis tef*) Production Assosa, Benishangul-Gumuz Regional State, Western Ethiopia. *Adv. Crop Sci. Technol*. 06, 1-3.

Habtegebrial, K., Singh, B.R. and Haile, M., 2007. Impact of tillage and nitrogen fertilization on yield, nitrogen use efficiency of tef (Eragrostis tef (Zucc.) Trotter) and soil properties. *Soil and Tillage Research*, 94 (1), pp.55-63.

Jabesa, K.B., Abraham, T. 2017. Effect of Different Row Spacing, Levels of Nitrogen and Phosphorus Fertilizers on Yield Attributes, Productivity and Economics of Tef (Eragrostis tef). *Int. J. Agric. Environ. Biotechnol*. 10, 603-608.

Kebede, H., Johnson, R.C., Ferris, D.M.1989.Photosynthetic response of (*Eragrostis tef*) to temperature. *Physiol. Plant*., 77, 262-266.

Kirby, E.J.M.1993. Effect of sowing depth on seedling emergence, growth and development in Barley and Wheat. *Field Crops Res*., 35, 101-111.

Minten, B., Taffesse, A.S. and Brown, P.2018. *The economics of teff: Exploring Ethiopia's biggest cash crop*. Intl Food Policy Res Inst.

Paff K. 2018. Asseng, S. A review of tef physiology for developing a tef crop model. *Eur. J. Agron.,* 94, 54-66.

Photiades, I. and Hadjichristodoulou, A.1984. Sowing date, sowing depth, seed rate and row spacing of wheat and barley under dryland conditions. *Field Crops Res*. 151–162.

Pinthus, M.J. 1974. Lodging in wheat, barley, and oats: The phenomenon, its causes, and preventive measures. *Adv. Agron*; 25, 209-263.

Pramod, S., Ashok, K.T, and Sunil, A.N. 2019.Seed pelleting: A technique of seed quality enhancement. Bhartiya Krishi Anusandhan Patrika; (34):142-144.

Shah, L., Yahya, M., Shah, S.M.A., Nadeem, M., Ali, A., Wang, J., Riaz, M.W., Rehman, S., Wu,W., Khan, R.M.2019. Improving lodging resistance: Using wheat and rice as classical examples. *Int. J. Mol. Sci*. 20, 4211.

Seyifu Ketema. 1993. Tef (*Eragrostis tef)* Breeding, genetic resources, agronomy, utilization and role in Ethiopian agriculture.

Seyifu Ketema.1983. Studies of Lodging Floral Biology and Bredding Techniques in Tef (*Eragrostis tef*); University of London: London, UK.

Solomon Chanyalew, Setotaw Ferede, Tebkew Damti, Tsion Fikre, Yazachew Genet, Worku Kebede, Kidist Tolosa, Zerihun Tadele and Kebebew Assefa. 2019. Significance and prospects of an orphan crop tef. *Planta*, 250(3), pp.753-767.

Sharma, S., Warren, J., Lofton, J., Henry, W., & Murley, C. (2019). *Optimum planting depth for uniform germination and emergence of corn*. Oklahoma Cooperative Extension Service.

Teetor, V.H., Schmalzel, C. and Ray, D.T., 2017. Growing sweet sorghum (*Sorghum bicolor* L.] moench) in clumps potentially reduces lodging in the arid-south western United States. *Industrial Crops and Products*, 107, pp.458-462.

Teresa Alex, K. Srinivasan and P. Murali Arthanari. 2017. Effect of Seed Pelleting and Foliar Nutrition on Growth and Yield of Summer Irrigated Sesame (*Sesamum indicum* L.). *Madras Agric. J.*, 104 (10-12): 350-353.

Van Delden, S.H. Ennos, A.R., Stomph, T.J. 2010. Analyzing lodging of the panicle bearing cereal tef (*Eragrostis tef*). *New Phytol. Vos, J*. 186, 696-707.

Vavilov NI. 1951. The Origin, Variation Immunity and Breeding of Cultivated Plants. (translated from the Russian by K. Starr Chester). The Ronald press co, New York.

WRB (World Reference Base). (2006). A framework for international classification, correlation and communication, world soil resource report 103 (pp. 68). Rome: Food and Agriculture Organization of the United NatioWürschum, T., Langer, S.M., Longin, C.F.H., Tucker, M.R., Leiser, W.L. 2017. A modern Green Revolution gene for reduced height in wheat. *Plant J.,* 92, 892–903.

Xue, J., Xie, R.Z., Zhang,W.F., Wang, K.R., Hou, P., Ming, B., Gou, L., LI, S. 2017. Research progress on reduced lodging of high-yield and -density maize. *J. Integr. Agric;* 16, 2717-2725.