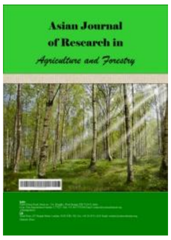

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Effect of Soil Compaction and Sowing Dates on Growth and Yield of Three Tef [*Eragrostis tef* (Zucc) Trotter] Varieties in Toke Kutaye District, Ethiopia

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Tef is a highly valued crop in Ethiopia as tef flour used to prepare Injera which is the most popular food of the country. However, its production and productivity are constrained by a number of problems, out of which soil compaction, inappropriate sowing time, and limited use of improved varieties are the most important. Hence, a field experiment was conducted during the 2021 main cropping season to evaluate the effect of soil compaction, sowing dates and tef varieties on yield and yield components of tef in Toke Kutaye district. Treatments were factorially arranged and laid out in randomized complete block design with three replications. Analysis of the data indicated that days to 50% emergence, days to 50% panicle emergence, days to 90% physiological maturity, and number of productive tillers of tef were significantly ($P<0.05$) influenced by main effect of soil compaction, sowing dates and varieties. Plant height, panicle length, number of total tillers, biomass yield, grain yield and straw yield of tef were significantly affected by the interaction of three factors. Highest plant height (124.26cm), panicle length (36.26cm), above ground biomass yield (7.47 t ha^{-1}), and grain yield (2.8 t ha^{-1}) were recorded from un-compacted soil, from early sown Dagim variety. Therefore, it can be recommended that farmers of the study area can grow Dagim variety early third week of july without trampling the soil to enhance the tef production and productivity.

Keywords: Soil compaction; sowing dates; tef; yield.

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1. INTRODUCTION

"Tef [*Eragrostis tef)* (*Zucc*.) *Trotter*] is a self-pollinated and warm season cereal crop originated in Ethiopia and have been domesticated and used in Ethiopia due to its excellent nutritional value as grains for human consumption and as feed for livestock" [1]. It has the largest value in terms of both production and consumption in Ethiopia.

"It is grown annually on 2.93 million hectares of land in Ethiopia with a total production of 5.51 million tons at an average productivity of 1.88 t ha^{-1}. Tef is grown by more than 6.86 million households and constitutes the major stable food grain for over 50 million Ethiopians" [2]. Tef is a highly-valued crop, as it is nutritionally rich and free of protein gluten.

"Oromia National Regional State is among the most important tef growing areas of Ethiopia which accounts for 1,393,455.62 ha of area coverage annually with expected production of 2.69 million tons with average productivity of 1.93 t ha^{-1}. On the other hand, West Shewa Zone accounts for 233,023 hectares of land and 4,765,75 tons of tef grain with average productivity of 2.05 t ha^{-1}" [2].

"However, soil compaction, inaccurate sowing date and shortage of high yielding varieties are crucial problems in the study area. Soil compaction increases root penetration resistance due to reduced soil porosity" [3]. "Moreover, compaction decreases air and water transport capability of soil due to its negative effects on soil hypoxia" [4]. "However, tef farmers in the study area compact the soil before sowing to make seedbed firm and flat, to prevent the soil surface from quick drying, to provide a thin coverage of broadcasted seeds and prevents seeds from desiccation and consequently enhances good germination and seedling establishment. Sowing date is another important factor which govern the phenological development of the crop and efficient conversion of biomass into economic yield. It has been observed that tef crop sown at normal date usually have longer crop duration, thus gets an opportunity to accumulate more biomass as compared to late sown and results in higher grain yield and biological yield" [5]. Therefore, this research was conducted to evaluate the effect of soil compaction and sowing dates on yield and yield components of tef varieties in Toke Kutaye district.

2. MATERIALS AND METHODS

"The study was carried out during the main rainy season from June to November, 2021 at *Wajira kebele*, Farmer's Training Center of Toke Kutaye district, West Showa Zone of Oromia National Regional State, Ethiopia. Toke Kutaye district is located at 100 km from Addis Ababa towards western direction. Geographically, the district is situated at latitude of $9.81^{o}47'$ to $10.08^{o}11'$N, longitude of $38^{o}27'$ to $38.67^{0}43'$E, with an altitude of 1500 to 3167 m above sea level" [6].

"It receives an average rainfall of 950 mm per annum with a minimum of 800 mm per annum and a maximum of 1100 mm per annum. The average temperatures were 17°C annually with a minimum of 15°C and a maximum of 29°C. The major agro-ecologies of the district are 25% high land, 57% mid land, and 18% low land. The major crops cultivated in the district are maize, tef, barley, wheat, sorghum, fababean etc" [6].

The treatment consisted of two levels of soil compaction (compacted and un-compacted soil), three dates of sowing such as early sowing date (July 15) = SD1, mid-sowing date (July 22) = SD2, and late sowing date (July 29) = SD3) and three varieties such as *Dagim, Quncho* and *Dedefe* (standard check). The treatments were laid-out in 2*3*3 factorial arrangement in RCBD design with three replications. The experiment consisted of 18 treatments which were assigned randomly to each plot. The spacing between blocks and plots was 1m and 0.5m respectively with net plot size of 2*3=6m².

The field was plowed four times using oxen and prepared according to local practices before planting. The first plowing was done at the onset of the rainfall on 10th May 2021 and the second ploughing was done after 21 days on 1st June 2021 and the third ploughing was done after 21 days on 22nd June 2021 and the last ploughing was at sowing. In accordance with the specifications of the design, a field layout was prepared. The soil was compacted and rows were made manually before sowing. Tef seeds were sown manually in rows. Both NPS and urea fertilizers were used for compacted soil and un-compacted soil in equal amount. 100kg/ha NPS fertilizer was applied as a basal application to each plot, and nitrogen at the specified rates 100kg/ha was applied in two splits in the form of urea (½ of the urea at sowing date and the remaining half was applied during tillering for optimum nutrient use efficiency of tef [7].

The seed rate used for all tef varieties were 10 kg ha^{-1}. The seeds were sown in rows and the spacing used between rows was 20 cm. Each plot had ten rows and out of which the first and tenth rows were considered as boarder rows, while the remaining eight rows were used for data collection. Weeds were removed manually at the early stages of tef. Harvesting was done manually using hand sickles at the physiological maturity of the crop.

2.1 Data Collected and Measurements

Crop growth, yield, and yield components were measured from each net plot across treatments using following sampling and analytical procedures.

Days to 50% emergence: This parameter of the plant was recorded as the number of days from sowing to the date when 50% of the plants in a plot started to emerge, through visual observation.

Days to 50% panicle emergence: This parameter of the plant was recorded as the number of days from sowing to the date when 50% of the plants in a plot started to emerge panicles, through visual observation.

Days to 90% physiological maturity: Days to physiological maturity was determined as the number of days from sowing up to the date when 90% of the plants reached physiological maturity based on visual observation.

Plant height (cm): It was measured at physiological maturity from the ground level to the tip of the main shoot panicle from ten randomly selected pre-tagged plants in each plot.

Panicle length (cm): It was the length of the panicle from the node where the first panicle branches emerge to the tip of the panicle measured as the main shoot panicle from ten randomly selected pre-tagged plants in each plot.

Grain yield: This was taken as the weight (kg) of the grains harvested from the net plot area after threshing and then converted to kg ha^{-1}.

Straw yield: After threshing, the straw yield was obtained by subtracting the grain yield from the total above-ground biomass yield.

“The data was subjected to analysis of variance (ANOVA) following the standard procedure given by Gomez and Gomez [8] and analysis was done using SAS software program version 9.0 (SAS, 2002). Means of significance between and among treatment effects were separated using the Least Significant Difference (LSD) test at 5% level of significance” [8].

3. RESULTS AND DISCUSSION

3.1. Days to 50% Emergence

The analysis of variance showed that days to 50% emergence of tef was significantly ($P<0.01$) affected by the main effect of soil compaction, sowing dates, and varieties (Table 1). However, their interactions were not significantly ($P<0.05$) influence days to 50% emergence.

The longest days to 50% emergence of 4.33 days was recorded on soil compaction treatment, while the shortest days of 3.85 days was recorded on un-compacted soil. This could be due to the effect of soil compaction on soil aeration and availability of oxygen which is essential for seed germination and its related metabolic activities such as respiration, which in turn affects the emergence of seedlings.

On the other hand, the longest days to 50% emergence of 4.27 days was recorded on lately sown treatment of July 29, 2021 and the shortest days to 50% emergence of 4.00 days was recorded from early sown treatment of July 15, 2021 which was statistically at par with mid-sown treatment of July 22, 2021. This is due to the fact that timely sown of tef can utilize the soil moisture available during early sowing dates, compared to late sown seeds. Similar results were obtained by Zucca [5] who reported that there was significant effect of different sowing dates on days to emergence of tef.

Days to emergence showed variability among varieties. The longest days to emergence of 4.19 days was recorded on variety *Dedefe*, while the shortest days to emergence of 3.97 days was obtained from variety *Quncho* (Table 1). This could be due to difference in seed size and their genetic variation.

3.2 Days to 50% Panicle Emergence

The analysis showed that days to 50% panicle emergence was significantly ($P< 0.001$) affected by the main effect of sowing dates and varieties, however soil compaction and the interaction of the main factors did not significantly ($P<0.05$) affect days to 50% emergence (Table 1).

The longest days to panicle emergence of 56.16 days was recorded from late sown treatment of July 29, 2021, which was statistically at par with mid-sown date, while the shortest days to panicle emergence of 52.94 days was recorded from early sown date of July 15, 2012. In late sown tef, panicle emergence was late, which might be due to unavailability of optimum moisture required for panicle emergence.

However, the longest days to attain 50% panicle emergence of 57.27 days was recorded from *Dagim*, while the shortest 50% panicle emergence of 52.11 days was recorded from *Dedefe* (Table 1). This might be due to ecological suitability of *Dedefe* as a result of timely sowing and genotypic advantage. Mebratu et al. [9] reported that improved varieties and local check significantly differ in days to panicle emergence in tef because of genotypic variation.

3.3 Days to 90% Physiological Maturity

The analysis of variance showed that days to 90 % physiological maturity was significantly (P<0.05) affected by main effect of soil compaction, sowing dates and varieties (Table 1). However, their interactions did not significantly (P<0.05) affect days to 90% physiological maturity.

The highest and lowest number of days of 130.96 and 129.33 days for 90% physiological maturity were recorded from un-compacted and compacted soils, respectively while the shortest days to achieve 90% physiological maturity of 128.61 days was recorded from lately sown tef sown on July 29, 2021 which was statistically at par with early sown tef on July 15. Where as, the longest days to physiological maturity of 131.72 days was recorded from mid- sown tef sown on July 22, 2021 (Table 1). This difference in days to reach physiological maturity might be due to the variation in availability of nutrients in the soil and the suitability of agro-climatic conditions for vegetative growth of plants.

However, the shortest days for 90% physiological maturity of 123.72 days was recorded from *Dedefe* variety, while the longest days to physiological maturity of 135.00 days was recorded from *Dagim* variety. The difference in days to reach physiological maturity among tef varieties could be due to their inherent genetic variability. Mebratu et al. [9] reported that improved varieties and local tef significantly differ in days to reach physiological maturity because of their genotypic variation.

3.4 Plant Height

The analysis of variance showed that plant height was significantly (P<0.001) affected by the main factors of soil compaction, sowing dates and varieties, as well as their interaction (Table 2).

Table 1. Main effect of soil compaction, sowing dates and varieties on phenological parameters of tef in Toke Kutaye district

Treatments	Days to emergence	Days to panicle emergence	Days to maturity
Compacted soil	4.33^{a}	54.51^{a}	129.33^{b}
Un-compacted soil	3.85^{b}	55.37^{a}	130.96^{a}
LSD (0.05)	0.13	NS	1.60
Sowing dates			
July 15,2021	4.00^{b}	52.94^{b}	130.11^{ab}
July 22,2021	4.00^{b}	55.72^{a}	131.72^{a}
July 29,2021	4.72^{a}	56.16^{a}	128.61^{b}
LSD (0.05)	0.16	1.70	1.97
Varieties			
Dagim	4.11^{ab}	57.27^{a}	135.00^{a}
Quncho	3.97^{b}	55.44^{b}	131.72^{b}
Dedefe	4.19^{a}	52.11^{c}	123.72^{c}
LSD (0.05)	0.16	1.70	1.97
CV (%)	6.03	4.59	2.24

Means with the same letter(s) in columns and rows are not significantly different at P<0.05 probability level

The tallest plant height of 124.27 cm was recorded from un-compacted soil with early sown *Dagim* variety, while the shortest plant height of 69.17 cm was recorded from late sown *Dedefe* variety on compacted soil (Table 2). The tallest plant height obtained from early sown *Dagim* variety on un-compacted soil exceed by 44.33% over the treatment that produced the shortest plant height. Soil compaction and delaying of sowing date might be the reason for decrease in plant height. The increase plant height might be due to adequate amount of nutrients which promoted the vegetative growth in treatments of early sowing date with *Dagim* variety on un-compacted soil and due to the inherent genetic differences among varieties. In addition, the difference in plant height of the varieties could be attributed to the difference in their genetic makeup [10]. Similarly, Zucca [5] reported tallest plant height of 95.3 cm in response to early sowing with on un-compacted soil while the shortest of 63.3 cm observed on delayed sowing dates and on compacted soil.

3.5 Panicle Length

Panicle length was significantly (P<0.001) affected by the main effect of soil compaction, sowing dates, varieties and their interaction (Table 3).

The longest panicle length of 36.26 cm was recorded from un-compacted soil with early sown on July 15, 2021 in *Dagim* variety, which was statistically at par with early sown on compacted soil, while the shortest panicle length of 22.80 cm was obtained on compacted soil with early sown date from *Dedefe* variety. The significant difference among the varieties for these growth traits might be attributed to their genetic difference which reflects on their different responses to sowing dates and soil compaction. Sherif [11] and Zucca [5] also reported that early sowing influenced increased panicle length in tef.

Table 2. Interaction effects of soil compaction, sowing dates and varieties on plant height of tef in Toke Kutaye district

Treatments	Compacted soils			Un-compacted soils			
Sowing dates	SD1	SD2	SD3	SD1	SD2	SD3	Mean
			Varieties				
Dagim	110.40[b]	97.70[f]	98.70[f]	124.27[a]	108.97[bc]	99.80[f]	106.64
Quncho	101.6[ef]	106.3[bcde]	102.6[ef]	105.07[cde]	102.8[def]	107.8[bcd]	104.16
Dedefe	75.00[gh]	79.03[g]	69.17[i]	74.87[gh]	78.60[g]	72.70[hi]	74.89
Mean	95.67	94.34	90.15	101.4	96.79	93.4	
LSD (0.05)			5.14				
CV (%)			3.26				

Where SD1; Early sowing date, SD2; Mid-sowing date, SD3; Late sowing date
Means with the same letter(s) in columns and rows are not significantly different at P<0.05 probability level.

Table 3. Interaction effects of soil compaction, sowing dates and varieties on panicle length of tef in Toke Kutaye district

Treatments	Compacted soils			Un-compacted soils			
Sowing dates	SD1	SD2	SD3	SD1	SD2	SD3	Mean
			Varieties				
Dagim	36.26[a]	30.73[cd]	28.76[ef]	36.33[a]	30.93[bcd]	32.00[bc]	32.5
Quncho	27.03[f]	31.56[bcd]	32.60[b]	30.36[cde]	30.10[de]	31.36[bcd]	30.5
Dedefe	22.80[i]	24.56[gh]	23.10[hi]	24.40[ghi]	25.16[g]	24.93[g]	24.12
Mean	28.69	28.95	28.15	30.36	28.73	29.43	
LSD (0.05)			1.73				
CV (%)			3.60				

Where SD1; Early sowing date, SD2; Mid-sowing date, SD3; Late sowing date
Means with the same letter(s) in columns and rows are not significantly different at P<0.05 probability level.

3.6 Grain Yield

Grain yield is the result of overall response of tef to different inputs, agronomic practices, ecological conditions and genetic differences. The analysis of variance revealed that the grain yield of tef was significantly (P<0.05) influenced by interaction of soil compaction, sowing dates and varieties (Table 4).

The highest grain yield of tef of 2.8 t ha^{-1} was recorded from early sown *Dagim* variety on un-compacted soil while the lowest grain yield of tef of 1.95 t ha^{-1} was recorded from late sown in *Dedefe* variety on un-compacted soil (Table 4).

The results of the study showed *Dagim* variety sown early on un-compacted soil increased grain yield by 30.35% over lately sown *Dedefe* variety. This is because of genotypic differences, appropriate sowing time, and un-compacted soil which contributed to high yielding ability as compared to local cultivar. Yield increase on early sown *Dagim* variety might be due to better translocation of photosynthesis to reproductive cells and accumulation of carbohydrates in grain as compared to delayed sowing. Juraimi et al. [12] and Zucc [5] reported that "there is a significant relationship among plant height, biomass, and grain yield where grain yield responded positively to taller plants and higher biomass when the crop was sown early in the season". Fazal et al., (2015) reported that delay in sowing date and genetic variation reduced the grain yield caused by smaller number of productive tillers and grains per spike in wheat. Juraimi et al. [12] and Mengistu [13] reported that early sown tef produced higher yield as compared with late sown.

3.7 Straw Yield

The analysis of variance showed that the interactions of sowing date and varieties significantly (P<0.001) affected straw yield (Table 5). The main factor of soil compaction and other interactions not significantly (P<0.05) affect straw yield.

The highest straw yield of 4.42 t ha^{-1} was obtained from early sown *Dagim* variety, while the lowest straw yield of 3.17 t ha^{-1} was recorded from lately sown *Dedefe* variety (Table 5). This difference in straw yield might be due to suitability of early sowing date and genotypic variation of *Dagim* variety which contributed for increasing straw yield.

Table 4. Interaction effects of soil compaction, sowing dates, and varieties on grain yield of tef

Treatments	**Compacted soils**			**Un-compacted soils**			
Sowing dates	SD1	SD2	SD3	SD1	SD2	SD3	Mean
			Varieties				
Dagim	2.66^{b}	2.54^{c}	2.23^{ef}	2.8^{a}	2.38^{d}	2.36^{d}	2.50
Quncho	2.41^{d}	2.28^{e}	2.12^{hi}	2.24^{ef}	2.18^{fgh}	2.16^{gh}	2.23
Dedefe	2.16^{gh}	2.15^{gh}	2.06^{i}	2.19^{fg}	2.13^{hi}	1.95^{j}	2.11
Mean	2.41	2.32	2.14	2.41	2.23	2.16	
LSD (0.05)			144.12				
CV (%)			3.81				

Where SD1; Early sowing date, SD2; Mid-sowing date, SD3; Late sowing date
Means with the same letter(s) in columns and rows are not significantly different at P<0.05 probability level

Table 5. Interaction effects of sowing dates and varieties on straw yield of tef

Sowing dates	SD1	SD2	SD3	Mean
		Varieties		
Dagim	4.42^{a}	3.64^{b}	3.46^{bcd}	3.84
Quncho	3.64^{b}	3.63^{bc}	3.33^{de}	3.54
Dedefe	3.37^{cde}	3.18^{d}	3.17^{e}	3.24
Mean	3.81	3.48	3.32	
LSD (0.05)		277.21		
CV (%)		6.67		

Where SD1; Early sowing date, SD2; Mid-sowing date, SD3; Late sowing date
Means with the same letter(s) in columns and rows are not significantly different at P<0.05 probability level

4. CONCLUSION

To conclude, results showed that the longest days to 50% emergence of 4.11 days and longest days for panicle emergence of 56.16 days were recorded from late sowing date. The longest days for panicle emergence of 57.27 days and the longest days for physiological maturity of 135 days were recorded from recently released *Dagim* variety. Compacting of soil in tef production also reduced duration for physiological maturity.

The tallest plant height of 124.26 cm, longest panicle length of 36.26 cm, the highest above ground biomass yield of 7.47 t ha^{-1} and the highest grain yield of 2.8 t ha^{-1} were obtained from un-compacted soil with early sown *Dagim* variety. *Dagim* variety was the best in overall performance in the study area. Early sown *Dagim* variety on un-compacted soil increased growth and yield of tef, highest grain yield (2.8 t $ha\text{-}^{1}$) was recorded from early sown *Dagim* variety on un-compacted soil. Therefore, it is advisable that farmers use *Dagim* variety on un-compacted soil with early sown date to increase tef production and productivity in Toke Kutaye district. In order to draw reliable recommendations, further study may be be conducted on similar topic and agro-ecology as the study was conducted for only one season and site.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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