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Evaluation of Fertilizer and Seed Rate Effect on Yield and Yield Component of Tef [Eragrostis tef (Zucc.) Trotter] on Vertisols in Central high-lands of Ethiopia

Sakatu Hunduma* Adane Buni
Ethiopian Agricultural Research Institute, Holetta Agricultural Research Center

Abstract
Tef [Eragrostis tef (Zucc.) Trotter] is among the major cereals of Ethiopia and occupies the largest cultivated land more than any other cereals. The need for its production as a staple food is increasing from year to year; however, its productivity is almost stagnant. Nutrient depletion is one of the major causes that contribute to declining in soil productivity in the highlands of Ethiopia. This experiment was conducted from 2012-2014 during the main cropping season to determine the optimum fertilizer and seeding rates for optimum grain yield of tef on high land vertisols. Factorial combination of 6 levels of tef seed rate (5, 10, 15, 20,25 & 30 kg ha-1) and 3 levels of fertilizer rates (34.5kg N/ha with 30kg P_2O_5/ha, 69 kg N/ha with 60kg P_2O_5/ha, & 103.5kg N/ha with 90 kg P_2O_5/ha) were compared in Randomized Complete Block with three replication. Results indicated that fertilizer rate significantly ($P< 0.01$) affects tef grain yield, biomass yield, plant height and number of fertile tiller per plant. Seed rate significantly ($P< 0.01$) affects the biomass yield of tef, panicle length and number of fertile tiller per plant but not significantly affects the tef grain yield and plant height. The interaction effect of seed rate and fertilizer rate was significantly ($P< 0.01$) affects the grain yield and biomass yield of tef but not significantly affects plant height, panicle length and number of fertile tiller per plant. The optimum tef grain yield (2239.1kgha^{-1}) was obtained using 20kg/ha tef seeding rate and 69kg N/ha with 60kg P_2O_5/ha fertilizer rate. Taking into account productivity and economic analysis, 20kg ha^{-1} tef seed rate and 69kg N/ha with 60kg P_2O_5/ha fertilizer rate on heavy black soil is recommended for main cropping season for tef production.
Keywords: fertilizer and seed rate, grain yield, marginal rate of return, tef, vertisol

1. Introduction

Tef [Eragrostistef (Zucc.) Trotter] is among the major cereals grown in Ethiopia. Tef production has been increasing from year to year and so does the demand for it as staple grain in both rural and urban areas of Ethiopia (Mitiku, 2008). Although tef is found in almost all cereal growing areas of Ethiopia, the major areas of production are Shewa, Gojam, Gonder, Wellega and Wello with central highlands of the country (Doris-Piccinin, 2010). It occupies about 3 million hectares (24.02% of the grain crop area) of land which is more than any other major cereals such as maize (16.8%), sorghum (14.58%) and wheat (13.25%) (CSA, 2014). Despite the fact that tef has widely grown under a wide range of altitudes (300 to 2800m above sea level), climate conditions, and soil types including which are marginal to most other crops (Seyfu, 1997; Hailu and Seyfu, 2001), the average grain yield in Ethiopia according to the central statistic agency (CSA, 2014) is about 15.75Q ha^{-1}. This average tef grain yield is low compared to other cereals, which is attributed to nutrient limitations, drought and water logging (Tulema *et al.,* 2005). By using improved cultivars and management practices, however, tef can yields up to 2500 kg ha^{-1} (Tefera and Belay 2006), while the yield potential under optimal management and when lodging is prevented, is as high as 4500 kg ha^{-1} (Teklu and Tefera 2005). Lower tef grain yield is mainly attributed to low soil fertility, especially, nitrogen and phosphorus deficiencies (Fassil and Charles, 2009).

Tef grains and flour do not contain gluten (Spaenij-Dekking *et al*., 2005) and are rich in minerals, especially iron (Yewlsew *et al*., 2007). These two characteristics make tef flour a desirable ingredient in health products. It is a highly valued crop primarily grown for its grain that is used for making *injera* (Abel, 2005). Tef is the only crop tolerates water logging. Improving crop production and productivity of tef on vertisol can be mainly achieved through integrating appropriate agronomic practices especially using optimum seeding and fertilizer rates. This help the crop to express its genetic potential with the help of enhanced soil environmental condition through supplying different nutrients and by maintaining optimum plant populations. Nitrogen and phosphorus deficiency is often encountered in tef and wheat growing areas of Ethiopia, in which the severity of the problems predominate the frequently water-logged soils of high land vertisols (Tekalign *et al*.,1988; Syers *et al.,* 2001). Grain and straw yield response of tef to increasing rates of N was highly significant on Vertisols (AUA, 1989). Yield of tef crop is low on high land vertisol probably due to the occurrence of accelerated soil erosion and lack of appropriate cultural practices on farmers' fields (Fufa *et al.,* 2001).

The main factors responsible for low tef yield also include less or more plant population and inadequate crop nutrition. Plant density is a major factor determining the ability of the crop to capture resources and generate yield. It can be developed by using a suitable seeding rate. In Ethiopia, a blanket recommendation of about 15-55 kg/ha of tef seed rates are used in different regions of the country (Seyfu, 1997). This makes it

difficult to control plant population and its distribution which may lead to higher competition for major growth factors such as light, nutrient and moisture. In order to increase the productivity per unit area, adoption of improved technology in fertilizer and seeding management is one of the major production limiting factors. So, this experiment was carried out with the objectives of evaluating optimum fertilizer and seed rate for optimum tef productivity on highland vertisol areas of Ethiopia.

2. MATERIALS AND METHODS

2.1 Study area

The experiment was conducted at Ghinchi ($09^0$03' N, $38^0$30' E), located in Dendi district, west showa zone, Oromia Regional State of the Democratic Republic of Ethiopia. The area has an altitude of 2200 meter above sea level. Average annual rainfall of the area is 1126 mm of which approximately 75% of the rainfall is received from June to September cropping period. Maximum temperatures rarely rise above 25^0C in summer and the minimum temperature fall to values around 5^0C in winter. The clay content of the experimental site in the 0-20 cm layer is above 60% and classified as pellic vertisol. The pH is slightly acidic with low total nitrogen content and medium available P with less organic matter content. The major crops of the area are tef, wheat, pulses and oil seeds. Water-logging, soil fertility depletion and erosion are the major crop production constraints on these soils.

2.2 Design and treatments

The experiment was carried out during the main rainy season of three years (2012-2014) to determine the appropriate fertilizer and seeding rates for the optimum grain yield of the crop tef in high-land vertisols of Ethiopia. The experimental plot size was $25m^2$. A factorial combination of six levels of seed rates (5, 10, 15, 20, 25 & 30 kg ha^{-1}) and 3 levels of fertilizers (34.5kg N/ha with 30kg P_2O_5/ha, 69 kg N/ha with 60kg P_2O_5/ha, & 103.5kg N/ha with 90 kg P_2O_5/ha) were arranged in Randomized Complete Block Design with three replications. Planting method was row planting with row spacing of 20 cm and as the soil was vertisol, ridge and furrow method of bed preparation was used in order to avoid excess water from the field. Tef variety, Kuncho (Dz-Cr-387) was used for this experiment. Urea and DAP used as source of N and P_2O_5 nutrients. All DAP and half of urea fertilizers were applied at planting according to the treatment levels assigned to each plot. The remaining half of urea fertilizer was applied at tillering stage soon after weeding on the same date. All recommended cultural practices were adopted for managing the experimental field.

2.3 Data collection and analysis

Plant height and panicle length were recorded from an average of ten representative plants randomly selected from each plot. Number of fertile tillers also recorded from ten representative plants selected by counting fertile tiller of each plant taking an average for each plot. Grain yield and biomass yield per net plot area were recorded and converted to kg/ha. All the data were subjected to analysis of variance (ANOVA) using the GLM procedure of SAS. The LSD test was used to separate significantly differing treatment means after they were found significant at $P \leq 0.05$. Economic analysis was made following CIMMYT methodology (CIMMYT, 1988). Regarding the input prices considered in economic analysis, the three year average cost of 100 kg Urea was 1100 Ethiopian birr (ETB) and that of 100 kg DAP was 1400 Ethiopian birr (ETB) and average tef grain price per 100 kg was 1300 Ethiopian birr (ETB) where 1$ is equal to 22 Ethiopian birr (ETB).

3. RESULTS AND DISCUSSION

3.1 Yield and yield components

The combined analysis of the data indicated that the main effect of fertilizer rate significantly affects grain yield, biomass yield, plant height and number of fertile tiller per plant. The main effect of seed rate not significantly affect grain yield and plant height but it significantly affects biomass yield, panicle length and number of fertile tiller per plant (Table 1).

3.1.1 Grain yield

The combined analysis of variance indicated that significant ($P< 0.01$) grain yield difference was seen due to both main effect of fertilizer rate and the interaction effect of fertilizer and seed rates. The combined analysis of the three year data showed that significant tef grain yield difference was obtained between different fertilizer rates tested but tef grain yield was not significantly affected by different tef seed rates tasted. Maximum mean grain yield (2239.1 kg/ha) was recorded using 20 kg/ha tef seed rate and 69 kg N/ha with 60 kg P_2O_5/ha fertilizer rate (Table 2). This result agrees with the findings of Alemayehu *et al*.; 2007 which reported that 60-80kgN/ha with 18-26kgP/ha is the best fertilizer recommendation for tef crop on vertisol. According to Mitiku (2008), there was a significant increase in yield components of tef with the decreasing seed rate from 35 to 20 kg/ha. The result also supports the work of Temesgen (2001) where the response of tef to N significantly ($p<0.01$) increased grain yield from 1620 kg/ ha in the check plot to 1920 kg ha-1 in plots with 69 N kg/ ha on Vertisols at

North Wollo.

3.1.2 Biomass yield

Biomass yield was significantly (P<0.01) affected both by seed rate and fertilizer rates and by their interaction effect. Biomass yield was linearly increasing with the increment of both seed rate and fertilizer rates where the highest biomass yield 7522.22 kg/ha was recorded by using 103.5kgN/ha with 90kg P_2O_5/ha fertilizer rate with 30kg/ha seed rate (Table 3).

These results agree with the study of Temesgen *et al.,* (2001) who observed a significant (p< 0.01) biomass yield response to N on vertisols in the central highlands of Ethiopia. Also, the results support the work of Temesgen (2001) who found that N application consistently increased the biomass yields of tef on farmers' fields.

3.1.3 Plant height, Panicle length and Number of fertile tiller per plant

The plant height was significantly affected by the main effect of fertilizer rates but it was not significantly affected by the main effect of seed rates and the interaction effect of seed rate and fertilizer rate (Table 4). The plant height was significantly increased with the increased application of fertilizer and this result supports the findings of Legesse (2004) and (Minale *et al*., 2004). Besides, this study was also in agreement with the on-farm fertility management trial carried out at Holetta agricultural research center in year 2000 at Welmera (Lemlem *et al.*, (2002).

Panicle length was significantly affected by the main effect of seed rate but fertilizer rate and interaction effect of seed rate and fertilizer rate were not significant to affect panicle length. Mitiku (2008) also reported significant increment of panicle length from 21 to 35 cm with an increase in N rates from 0 to 90 kg/ha. Number of fertile tiller per plant was significantly affected both by main effect of seed and fertilizer rates but not by their interaction effect. The highest value of plant height (93.4cm), panicle length (31.4cm) and the highest number of fertile tiller per plant (4) were recorded by application of 103.5kgN/ha with 90 kg P_2O_5/ha. In general, optimum availability of nutrients in the soil plays an important role in the development of yield components of a crop.

3.2 Partial economic analysis

According to the results of the partial budget analysis, out of all treatments tasted the highest net benefit (Birr 19289.76 ha $^{-1}$) was obtained from the application of 69 kg N/ha with 60 kg P_2O_5/ha fertilizer and using 20kg/ha tef seed rate. The net benefit (Birr 10381.94 ha^{-1}) obtained from the application of 34.5kgN/ha with 30 kg P_2O_5/ha and using 5kg/ha seed rate was the lowest. The results of dominance analysis shows that out of eighteen treatments seven treatments are dominated (Table 5). Since no beneficiary will prefer alternatives that give lower net benefits than net benefit of the alternative with lower total costs that vary, the dominated treatments were eliminated from further economic analysis.

The highest marginal rate of return for the non-dominated treatments was 5790.5% (Table 6) which was recorded at treatment combination of 20kg/ha tef seed rate and 69 kg N/ha with 60 kg P_2O_5/ha fertilizer rate. This implies that for each birr 1.00 investment in tef production, the producer can get birr 1.00 and additional birr 57.9. In conclusion, out of the tasted treatments, the maximum net benefit and highest marginal rate of return was obtained by using 69 kg N/ha with 60 kg P_2O_5/ha fertilizer rate and 20kg/ha tef seed rate.

4. CONCLUSION AND RECOMMENDATIONS

Tef is among the major cereals and is an indigenous cereal crop to Ethiopia. Ethiopian farmers grow tef for a number of merits, which mainly attributed to the socio-economic, cultural and agronomic benefits. Both its grain and straw obtain relatively higher price than other cereal crops. Tef has got many prospects outside Ethiopia due to its gluten-free grains, tolerance to biotic and abiotic stresses, animal feed value and erosion control quality. Regardless of its high area coverage, adaptation to different environmental conditions and importance as a staple food in Ethiopia, the yield of tef grain is relatively low as compared to other major cereals. Its low productivity may be attributed due to several production problems like growing on marginal soils which are old method of cultural practices, low application of fertilizers, and soil-related constraints.

This research work was designed to determine appropriate seed and fertilizer rate for optimum tef yield production on high-land vertisol areas of Ethiopia. The general trend of data from field experiment conducted for three years indicated that the fertilizer rate effect is more crucial than seed rate effect on yield response of tef crop on vertisols. Results indicated that fertilizer rate significantly affects tef grain yield, biomass yield, plant height and number of fertile tiller per pant but seed rate significantly affect the biomass yield of tef, panicle length and number of fertile tiller per plant but not significantly affect the tef grain yield and plant height. Interaction effect of seed rate and fertilizer rate significantly affects the grain yield and biomass yield of tef but not significantly affects plant height, panicle length and number of fertile tiller per plant. The maximum net benefit (Birr 19289.76 ha $^{-1}$) and highest marginal rate of return (5790.5%) was recorded at treatment combination of 20kg/ha tef seed rate and 69 kg N/ha with 60 kg P_2O_5/ha fertilizer rate. Taking into account both

productivity and economic analysis, 20kg ha^{-1} tef seed rate and 69kg N/ha with 60kg P_2O_5/ha fertilizer rate can be recommended seed and fertilizer rate for main cropping season tef production on vertisol in central high-land areas of Ethiopia.

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Table 1. Table 1: Analysis of variance table showing the main and interaction effect of fertilizer and seed rates on tef yield components on vertisol (2012-2014).

Source of variation	Variables tasted				
	Grain yield (kg/ha)	Biomass yield (kg/ha)	Plant height (cm)	Panicle length(cm)	No. of fertile tillers/plant
Fertilizer rate (FR)	**	**	**	ns	**
Seed rate (SR)	ns	**	ns	**	**
FR * SR	**	**	ns	ns	ns
Mean	1798.8	5184.39	94.63	31.92	3.79
CV(%)	13.5	17.95	10.34	11.77	13.15

NB: FR = fertilizer rate; SR= seed rate; **,= significant at 1% probability levels; ns= non significant at 5% probability levels.

Table 2: Interaction effect of fertilizer rate and seed rate on tef grain yield (2012-2014)

	Seed rate (kg/ha)						
N/P_2O_5 ($kgha^{-1}$)	5	10	15	20	25	30	Mean
34.5/30	1310.5e	1423.8e	1399.1e	1420.1e	1386.7e	1477e	**1402.86**
69 /60	1934.5dc	2084.8	1902.5dc	**2239.1a**	1987abcd	1831.1dc	**1996.5**
103.5/90	1974.2bdc	2070abc	1951.4bdc	1754d	2025abc	2206ab	**1996.76**
Mean	**1739.73**	**1859.53**	**1751**	**1804.4**	**1799.56**	**1838.03**	**1798.711**
$LSD_{0.05}$	**259.6**						
CV(%)	**13.5**						

NB: Means followed by the same letter within a table are not significantly different at 5% level of significance

Table 3: Interaction effect of fertilizer and seed rates on tef biomass yield (2012-2014)

	Seed rate (kg/ha)						
N/P_2O_5 ($kgha^{-1}$)	5	10	15	20	25	30	Mean
34.5/30	3391.1e	4351.85e	4930.37cde	4339.25e	4462.96de	4673.29cde	**4358.138**
69 /60	4831.1cde	5020bcde	4898.51cde	5595.55cbd	5592.59cbd	5763.7bc	**5283.563**
103.5/90	5182.2bcde	5623.7cbd	5648.88cbd	5290.37bcde	6201.48b	7522.22a	**5911.478**
Mean	**4468.147**	**4998.49**	**5159.253**	**5075.057**	**5419.01**	**5986.403**	**5184.393**
$LSD_{0.05}$	1190.1						
CV(%)	17.95						

NB: Means followed by the same letter within a table are not significantly different at 5% level of significance

Table 4. Main effect of fertilizer and seed rates on yield and yield components of tef on vertisol (2012-2014)

Fertilizer rates N/P_2O_5($kgha^{-1}$)	Variables tasted				
	Grain Yield (Kg/ha)	Biomass yield (kg/ha)	Plant height (cm)	Panicle length (cm)	No. of Fertile tillers/plant
34.5/30	1402.92b	4358.1c	89.3b	32.4a	3.4b
69 /60	1996.51a	5283.6b	97.23a	32.13a	3.9a
103.5/90	1997.04a	5911.5a	97.37a	31.24a	4.07a
Seed rates (kg/ha)					
5	1739.74a	4468.1c	92.22a	30.5b	4.2a
10	1859.71a	4998.5b	93.74a	30.03b	4.01ab
15	1751.02a	5159.3b	96.81a	33.94a	3.86ab
20	1804.43a	5075.1b	9496a	32.06ab	3.84ab
25	1799.74a	5159.3b	95.43a	32.54ab	3.54bc
30	1838.29a	5986a	94.63a	32.42ab	3.2c
CV(%)	13.5	17.95	10.34	11.77	13.15

NB: Means followed by the same letter in a column are not significantly different at 5% level of significance.

Table 5: Cost-benefit and dominance analysis of Seed and fertilizer rate effects on tef grain yield on vertisols

Treatments			**12.5 % Adjusted yield (kg/ha)**	**Total Variable Cost (Birr/ha)**	**Gross benefit (Birr/ha)**	**Net benef (Birr/ha)**	**Dominated**
Fertilizer rates N/P_2O_5 ($kgha^{-1}$)	**Seed rates (kg/ha)**	**Unadjusted Yield (kg/ha)**					
34.5/30	5	1310.5	1146.688	4525	14906.94	10381.94	
34.5/30	10	1423.8	1245.825	4590	16195.73	11605.73	
34.5/30	15	1399.2	1224.3	4655	15915.9	11260.9	Dominated
34.5/30	20	1420.1	1242.588	4720	16153.64	11433.64	
34.5/30	25	1386.7	1213.363	4785	15773.71	10988.71	Dominated
34.5/30	30	1477	1292.375	4850	16800.88	11950.88	
69 /60	5	1934.5	1692.688	5985	22004.94	16019.94	
69 /60	10	2084.8	1824.2	6050	23714.6	17664.6	
69 /60	15	1902.5	1664.688	6115	21640.94	15525.94	Dominated
69 /60	**20**	**2239.1**	**1959.213**	**6180**	**25469.76**	**19289.76**	
69 /60	25	1987	1738.625	6245	22602.13	16357.13	Dominated
69 /60	30	1831.1	1602.213	6310	20828.76	14518.76	Dominated
103.5/90	5	1974.2	1727.425	7445	22456.53	15011.53	
103.5/90	10	2070.4	1811.6	7510	23550.8	16040.8	
103.5/90	15	1951.4	1707.475	7575	22197.18	14622.18	Dominated
103.5/90	20	1754	1534.75	7640	19951.75	12311.75	Dominated
103.5/90	25	2025.5	1772.313	7705	23040.06	15335.06	
103.5/90	30	2206.7	1930.863	7770	25101.21	17331.21	

NB: Three years average price of tef is Ethiopian birr (ETB) 13 /kg, Urea Ethiopian birr (ETB) 11/kg and DAP Ethiopian birr (ETB) 14/kg (1$=21.4 Ethiopian birr).

Table 6: Marginal Rate of Return analysis of fertilizer and seed rate effect on tef grain yield on vertisol

Treatments							
Fertilizer rates N/P_2O_5($kgha^{-1}$)	**Seed rates (kg/ha)**	**Unadjusted Yield (kg/ha)**	**12.5 % Adjusted yield (kg/ha)**	**Total Variable Cost (Birr/ha)**	**Gross benefit (Birr/ha)**	**Net benef, Birr/ha**	**MRR (%)**
34.5/30	5	1310.5	1146.688	4525	14906.94	10381.94	-
34.5/30	10	1423.8	1245.825	4590	16195.73	11605.73	1882.75
34.5/30	20	1420.1	1242.588	4720	16153.64	11433.64	265.75
34.5/30	30	1477	1292.375	4850	16800.88	11950.88	1480.25
69 /60	5	1934.5	1692.688	5985	22004.94	16019.94	358.5077
69 /60	10	2084.8	1824.2	6050	23714.6	17664.6	2530.25
69 /60	**20**	**2239.1**	**1959.213**	**6180**	**25469.76**	**19289.76**	5790.5
103.5/90	5	1974.2	1727.425	7445	22456.53	15011.53	43.4152
103.5/90	10	2070.4	1811.6	7510	23550.8	16040.8	1583.5
103.5/90	25	2025.5	1772.313	7705	23040.06	15335.06	4651.25
103.5/90	30	2206.7	1930.863	7770	25101.21	17331.21	3071

NB: MRR= Marginal Rate of Return, three years average price of tef is 13 /kg Ethiopian birr (ETB), Urea 11/kg Ethiopian birr (ETB) and DAP 14/kg Ethiopian birr (ETB) (1$=21.4 Ethiopian birr).