Refining Fertilizer Rate Recommendation for Teff (*Eragrotis tef (Zucc.) Trotter*) in Different Agro-Ecological Zones of Ethiopia: the case for Jamma District, South Wollo Zone, Amhara Region

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Abstract

A field study was conducted for two years to determine the yield response of tef to application of nitrogen (N), phosphorous (P) and sulfur (S) fertilizers under balanced fertilization. The study comprised of three separate studies: 1. Seven levels of N (0, 23, 46, 69, 92, 115, 138 kg ha^{-1}), 2. Six levels of P (0, 23, 46, 69, 92, 115 kg P_2O_5 ha^{-1}) and 3. Six levels of S (0, 10, 20, 30, 40, 50 kg ha^{-1}). One negative (-Ve;0,0,0 kg ha^{-1}, N, P and S) and one positive (+Ve) control treatments (recommended NP i.e 69/46 N/P_2O_5 kg ha^{-1}) were included in all studies. Balanced nutrients of 69/80/30/2/1 P_2O_5/K_2O/S/Zn/B for N; 92/90/30/2/1 N/K_2O/S/Zn/B for P; and 92/69/90/2/1 N/P_2O_5/K_2O/Zn/B for S response studies were applied to all treatments except to the Ve and +Ve control treatments. The treatments were laid in a randomized complete block

fields. The result revealed that there was a significant ($P \leq 0.01$) yield response to the application of N fertilizer. A quadratic response curve (R^2=0.988) was found the best fitting curve to explain the relationship between the grain yield and the N levels applied. The yield response curve showed that the grain yield increased significantly up to 92 kg N ha^{-1} and declined beyond this rate. Tef yield response study to P fertilizer showed a significant response to P at 50% of the testing sites. Although there was a significant treatment by site interaction effect on the yield, the average effect across all the testing sites and the yield response curve indicated that application of 23 kg P_2O_5 ha^{-1} was the agronomic optimum rate to maximize yield of tef. Application of S, however, was not found to have a significant effect on the yield of tef at all testing sites. Therefore, the application of S cannot be recommended for tef production in the district.

Keywords: Balanced nutrients, Fertilization, Nitrogen, Phosphorous, Sulfur

Introduction

Tef [*Eragrostis tef (Zucc*.)] is the most important cereal crop in Ethiopia covering 29.7% of the area and 19.5% of the total cereal production (CSA, 2019). It is rich in minerals, especially iron and it is also an excellent source of essential amino acids, especially lysine, the amino acid that is most often deficient in grain foods (Abebe *et. al.* 2007; Berhane *et.al.* 2011). It has also recently been receiving global attention particularly as a 'health food' due to the absence of gluten and gluten-like proteins in its grains (Spaenij *et. al.* 2005). In addition to its importance as a staple food, tef straw is important for fodder and use in house construction (Teklu and Tefera, 2005). However, the productivity of tef is very low as the country's national average yield is in the order of 1.76 t ha^{-1} (CSA, 2019).

One of the factors responsible for the low yield is soil fertility depletion (Stoorvogel and Smaling, 1990; Tulema, 2005). Ethiopia is one of the sub-Saharan African countries with the highest rates of nutrient depletion due to erosion, leaching, limited return of organic residues and manure and high biomass removal. Amare *et. al.* (2006) pointed out that management-related N and K fluxes in the tef-based cropping system were -28 kg N $ha^{-1}yr^{-1}$ and -34 kg K ha^{-1} yr^{-1}. As a result, replenishment of the soil nutrient reserve through fertilization with organic or inorganic sources is essential. Studies show that N and P are the most critical growth-limiting nutrients impeding crop production (Asnakew *et. al.,* 1991; Fassil and Charles, 2009) although recent studies indicated a deficiency of K, S, Zn and B (Habtegebrial and Singh, 2006; Bereket *et. al.* 2011; EthioSIS, 2014).

Current fertilizer recommendation for tef in the study area is very old and was based only on nitrogen and phosphorus fertilizers (50 kg DAP and 81 kg Urea ha^{-1}) (Yared *et. al.* 2003, unpublished). Therefore, refinement of the previous site-specific fertilizer recommendations under balanced fertilization is essential from the basis of the dynamic property of soils as a result environmental changes such as climate change and repeated cultivation without replenish ment. Fertilizer recommendations are usually generated based on field crop-nutrient-response studies under balanced fertilization, which was lacking for tef production in the present study District. Therefore, this research was conducted to develop the yield response curve of tef to N, P and S fertilizers under optimum supply of major micro nutrients.

Materials and method

Study site description

The study was conducted in 2014 and 2015 in Jamma District of South Wollo Zone of the Amhara Region. The district is situated within the geographical boundaries of 10^o 06’ 24’’ - 10^o 35’ 45’’ N latitudes and 39^o 04’ 04’’ - 39^o 23’ 03’’ E longitudes and altitudinal ranges of 1428 - 2752 meters above sea level (m.a.s.l). The district receives a mean annual rainfall of 1130 mm. The mean minimum and maximum temperatures of the district are 9 and 21 ^{o}C, respectively. The monthly rainfall distribution of the district in 2014 and 2015 is described in Figure 1 below. The dominant soil type for the District is Pellic Vertisols and some chemical properties of surface soil (0-30 cm) of the study sites are given below (Table 1).

Table 1. Some chemical properties of surface soil (0-30 cm) of the study sites

	2014			2015		
Soil parameters	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Organic matter (%)	1.15	1.15	1.90	1.49	2.04	1.72
Total N (%)	0.08	0.06	0.10	0.31	0.22	0.25
Available P (mg kg^{-1})	26.4	20.8	28.5	25.1	27.2	21.4

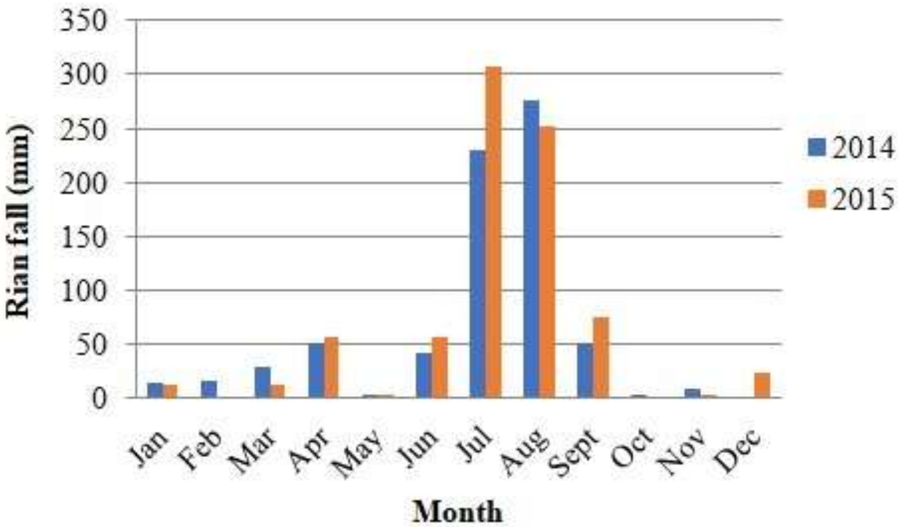

Figure 1. Monthly rainfall distribution of Jamma District in 2014 and 2015

Treatments and experimental design

The research comprised three separate studies; determination of yield responses of tef to N, P and S nutrients under balanced fertilization. Each of the nutrient response studies were conducted on three representatives randomly selected testing sites. Different levels of each nutrient, as described in Table 2 below, were evaluated separately under balanced fertilization. Seven rates of N (0, 23, 46, 69, 92, 115 and 138 kg ha^{-1}), six rates of P (0, 10, 20, 30, 40 and 50 kg P ha^{-1}) and six rates of S (0, 10, 20, 30, 40 and 50 kg ha^{-1}) were evaluated separately with application of sufficient balanced fertilizers (Table 2). In all nutrient response studies, absolute control (negative control; 0,0, 0 kg ha-1 N, P and S) and recommended NP (69/46 N/P_2O_5 kg ha^{-1}) as a positive control both without balanced fertilizer were included. The treatments were laid in a randomized complete block design (RCBD) with three replications.

Table 2. Treatments for the yield response studies of the three nutrients (NPS)

Nutrient levels	Balanced nutrients (kg ha^{-1})				
1. Nitrogen treatments (N kg ha^{-1})	P_2O_5	K_2O	S	Zn	B
0, 23,46, 69, 92,115 and 138	69	80	30	2	1
2. Phosphorus treatments (P kg ha^{-1})	N	K_2O	S	Zn	B
0, 10, 20, 30, 40 and 50	92	90	30	2	1
3. Sulfur treatments (S kg ha^{-1})	N	P_2O_5	K_2O	Zn	B
0, 10, 20, 30, 40 and 50	92	69	90	2	1

Nutrient sources: N=urea, P=Triple Super Phosphate (TSP), K= Muriate of Potash (KCl), S= $CaSO_4$, Zn=$ZnSO_4$, B = Borax

Experimental materials and procedures

In the first experimental year, the test crop was planted in a row with a 20 cm spacing and seeding rate of 10 kg ha^{-1} on the flat fine seedbeds. In the second year, it was planted by broadcasting with a seeding rate of 25 kg ha^{-1}. The variety *dega tef - DZ675* was used as a test crop. Phosphorus, K and S fertilizers were applied as Triple Super Phosphate (TSP), muriate of potash (KCl) and calcium sulfate ($CaSO_4$) straight fertilizers, respectively, in a row all at planting in the first year and broadcasted in the second year. While, N was applied as urea in split, at planting and top dressed at 45 days after planting. The micronutrients Zn ($ZnSO_4$) and B (Borax) were applied as foliar application 45 and 60 days after planting, respectively (Figure 2).

Figure 2. Foliar application of Zn and B micronutrients 45 and 60 days after planting, respectively

Data collection

Grain yield was measured by taking the weight of the grains threshed from the harvestable area of each plot and converted to kilograms per hectare. While, straw yield was obtained as the difference between dry biomass and grain yield. The dry biomass weight was measured by taking a straw sample with the seed spikes, drying in an oven at 105 ^{o}C for 12 hours and adjusting the fresh biomass weight on to dry basis by using the moisture content measured after an oven-dry.

Data analysis

Analysis of variance (GLM procedure) using SAS software version 9.00 (SAS Institute, 2004) was used to test the significance of the treatment's effect on the yield of tef. The mixed model procedure was used for the combined analysis over the testing sites in which each nutrients N, P and S were considered as a fixed variable while site and replication were considered as random variables. Significant differences between treatment means were delineated by Duncan’s Multiple Range Test (DMRT) method at $P \leq 0.05$. Simple regression analysis was run using SAS to determine the significance of the relationship between yield response and nutrients.

Results and discussion

Yield Response of Tef to Nitrogen Fertilizer

In the first year (2014), there was a significant ($P \leq 0.01$) yield response to N at all testing sites (Table 3). The maximum grain yields were recorded from application of 138 kg N ha^{-1} and 115 kg N ha^{-1} which were statistically at par with the grain yields obtained from application of 23, 46 and 69 kg N ha^{-1} at testing sites 1, 2 and 3, respectively. The significant yield response of tef to N in all testing sites was attributed to the low indigenous total N ($\leq$0.1%) of surface soil of the study site (Table 1), while the significant yield response variation to N at the three testing sites was attributed to the difference in the total N status of surface soil of the sites (Table 1).

However, in the second year (2015), it was only on one testing (Site 1) that the application of N was found to have a significant ($P \leq 0.01$) effect on the yield of tef. Application of 69 kg N ha^{-1} was found to give statistically equivalent grain yield with the grain yields obtained from 115 and 138 kg N ha^{-1} (Table 3). At testing sites 2 and 3, however, the yield of tef was not significantly ($P > 0.05$) affected by the application of N. This was due to the relatively better N nutrient existed in these sites as the sites were newly cultivated fields which were range lands previously. This was also confirmed from the high yields obtained from the –Ve control treatments from these sites.

The pooled analysis over the two experimental years and four testing sites (excluding those two sites in the second experimental year where there was no yield response to application of N) revealed that though the maximum grain yield was obtained from application of 138 kg N ha^{-1}, statistically ($P > 0.05$) equivalent grain yield were recorded from application of 92 kg N ha^{-1} (Table 3). Significant ($P \leq 0.05$) grain yield advantages of 31.5, 71.8, 81.2, 94.3 and 107.6% over the zero N-treated plot were obtained from application of 23, 46, 69, 92 and 115 kg N ha^{-1}, respectively. The significant yield difference recorded in the 2014 and 2015 cropping years was due to the higher amount of rainfall and its better distribution in the growing period in 2015 which favored the yield in 2015 (See rainfall pattern on Figure 1).

Table 3. Teff grain yield (kg ha^{-1}) affected by N rates at Jamma (2014, 2015 and combined over years)

Treatment* (N kg ha^{-1})	2014			2015			Combined
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
-Ve control	642.8b	603.7c	827.0d	683.3d	2152.5	1765.0ab	721.6e
0	633.9b	708.8bc	898.6cd	725.0d	2243.3	1858.3ab	741.6e
23	960.1ab	704.3bc	1041.6bcd	1318.3c	2015.0	1881.7ab	975.1d
46	1050.3ab	948.2ab	1063.1bc	1841.7b	1935.0	2066.7a	1273.9c
69	1087.5ab	920.3ab	1163.4ab	2203.3ab	2189.9	1531.7bc	1343.7bc
92	1397.7a	1004.8a	1133.9ab	2228.3ab	2053.3	1546.7bc	1441.2ab
115	1390.8a	1049.1a	1309.8a	2346.7a	2038.3	1686.7ab	1539.4a
138	1497.6a	1062.2a	1186.3ab	2356.7a	1970.0	1260.0c	1544.0a
+Ve control	1235.5a	878.0abc	1145.3ab	1861.7b	2495.0	1826.7ab	1290.4bc
CV (%)	26.5	17.3	11.3	14.1	17.6	12.1	14.8
SEM	292.0	151.5	122.5	243.9	372.4	207.4	179.5
Trt*Site	-	-	-	-	-	-	**

**Treatments means within a column followed by the same letter are not significantly different at p = 0.05. ** = significant at p=0.01.*

Many nutrient response studies in Ethiopia also revealed that tef responds significantly to N fertilization especially in the highland Vertisols (Temesgen, 2001; Tulema et al., 2005; Alemayehu et. al., 2007; Habtegebrial et. al., 2007; Wakene and Yifru., 2013). Research conducted at Sirinka by Legesse (2004) also indicated that as applied N rates increased the grain uptake also increased which also reflected in the yield and yield components of tef like panicle length, grain yield, straw yield and biomass yield. Earlier studies by Tekalign *et. al*. (2002) confirmed that 60 kg N ha^{-1} is the optimum rate of N fertilizer. In a research report by Fissehaye *et. al.*, 2009, it is stated that maximum grain yield was recorded from the application of 69 kg N ha^{-1} on Vertisols. However, a study by Kumela and Thomas (2016) showed that a higher rate of N at 80 kg N ha^{-1} along with P (80 P_2O_5 kg ha^{-1}) with tef row planting spacing of 10 cm was found to give the highest yield.

Yield response trend to application of N

When each yield data collected (excluding those sites where there was no significant yield response to N) is plotted against the N level applied, the yield response trend to N looks like as shown in Figure 3. It showed an increasing and predictable pattern with a quadratic curve (R^2 =

0.3122**) found to be the best fitting curve. Similarly, the response curve of the average grain yield data pooled over the four testing sites indicated that the grain yield was increased with a predictable trend as the level of N was increased (Figure 4). The quadratic response curve was found the best fitting curve with R^2=0.988 to explain the relationship between the grain yield and the N level applied (Figure 4).

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Figure 3. Grain yield data in response to N from all testing sites; GY = Grain yield in kg ha^{-1} and N = nitrogen rate in kg ha^{-1}

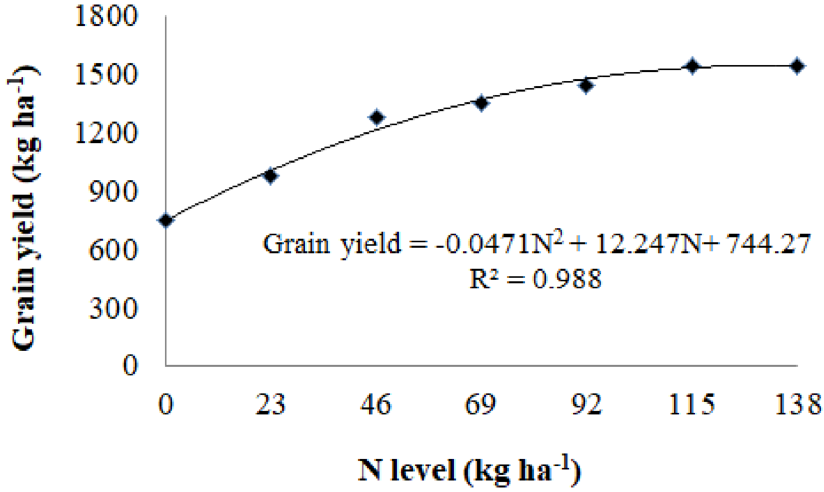

Figure 4. The mean yield response curve to N pooled over years and testing sites

Yield Response of Tef to Phosphorus Fertilizer

Yield response of tef to P fertilizer in the first experimental year showed that except at one testing site, the effect of application of P fertilizer on the grain yield of tef was not found significant ($P>0.05$). Instead, the application of P was found to have a negative effect on the yield of tef on the two testing sites. But, at one of the testing sites (Site 2), a significant ($P\leq0.05$) yield difference from the control (zero P treated plot) was obtained due to the application of 23 kg P_2O_5 ha^{-1} (Table 4). However, in the second experimental year, the application of P was found to have a significant ($P\leq0.01$) effect on the yield of tef (Table 4). The highest grain yields of 2.6 and 1.6 t ha^{-1} at testing sites 1 and 2, respectively, were obtained from the application of 23 kg P_2O_5 ha^{-1}, while, at testing site 3, the highest grain yield was obtained from the application of 46 kg P_2O_5 ha^{-1}. It was on 50% of the testing sites that a significant ($p\leq0.05$) yield response to the application of P fertilizer was found.

The pooled analysis over the six testing sites revealed that the maximum grain yield was recorded from the application of 69 kg P_2O_5 ha^{-1} which was statistically at par with the yield obtained from the application of 23 kg P_2O_5 ha^{-1} (Table 4). There was a significant ($P\leq0.01$) interaction effect of site with treatments on the yield indicating a variability of yield response to the application of P across the testing sites. The lack of response to P fertilizer application on 50% of the testing sites could be attributed to the optimum level of available P in the surface soil of the testing sites (Table 1).

Thus, application of 23 kg P_2O_5 ha^{-1} was found to be the optimum rate for those sites exhibiting significant yield response to application of P and could be used as a maintenance level for those sites which showed non-significant yield response to addition of P fertilizer. The other reason for the non-significant yield response to the addition of P fertilizer might be due to the high P sorption capacity of Vertisols (Sahrawat *et al.,* 1995; Abunyewa *et al.,* 2004) due to the high clay content of the soils which leads to increased surface area for P adsorption. The higher the amount of P adsorbed by the soil and its constituents, the less P will be available for plant uptake (Rashmi *et al.,* 2014).

Table 4. Grain yield (kg ha-1) response of tef to the addition of P fertilizer at the six testing sites in 2014, 2015 and combined over years

Treatment*	2014			2015			Combined
(kg P_2O_5 ha^{-1})	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
-Ve control	760.5d	478.5^{d}	477.3^{c}	673.3^{c}	506.7^{c}	722.5^{e}	583.7^{c}
0	1339.3^{a}	837.3^{bc}	1101.5^{a}	2048.3^{b}	1240.0^{b}	1480.1^{cd}	1401.4^{b}
23	1258.8^{abc}	904.5^{abc}	780.7^{b}	2573.3^{a}	1591.7^{a}	1313.3^{d}	1595.7^{a}
46	1215.6^{abc}	820.1^{bc}	923.6^{b}	2160.8^{ab}	1325.0^{ab}	1982.6^{a}	1572.1^{a}
69	1329.8^{ab}	938.2^{ab}	909.8^{b}	2245.8^{ab}	1403.3^{ab}	1833.3^{ab}	1605.2^{a}
92	1292.8^{abc}	932.1^{abc}	792.0^{b}	2138.3^{ab}	1355.0^{ab}	1745.7^{abc}	1542.8^{ab}
115	1190.6^{bc}	1065.1^{a}	885.4^{b}	2208.3^{ab}	1383.3^{ab}	1663.3^{abc}	1580.0^{a}
+Ve control	1161.0^{c}	756.7^{c}	872.2^{b}	2091.7^{ab}	1348.3^{ab}	1651.7^{bc}	1462.1^{ab}
CV (%)	6.2	11.0	11.7	12.5	13.9	10.3	12.7
SEM	74.5	92.6	98.4	252.4	177.5	163.2	180.6
Trt*Site	-	-	-	-	-	-	**

**Means within a column followed by the same letter are not significantly different at p = 0.05.* ** *= significance at 1% probability level.*

Trend of yield response to P

The yield response curve of the grain yield data from all testing sites in the two experimental years revealed that there was less predictable and nonsignificant relation ($r^2=0.0012^{ns}$) between the grain yield and the P fertilizer applied (Figure 5). However, the P yield response curve of the mean grain yield data of treatments pooled over years and testing sites as shown in Figure 6 below, showed that there was a strong relation ($R^2=0.6612$ or 66.1%) of grain yield to the addition of P fertilizer.

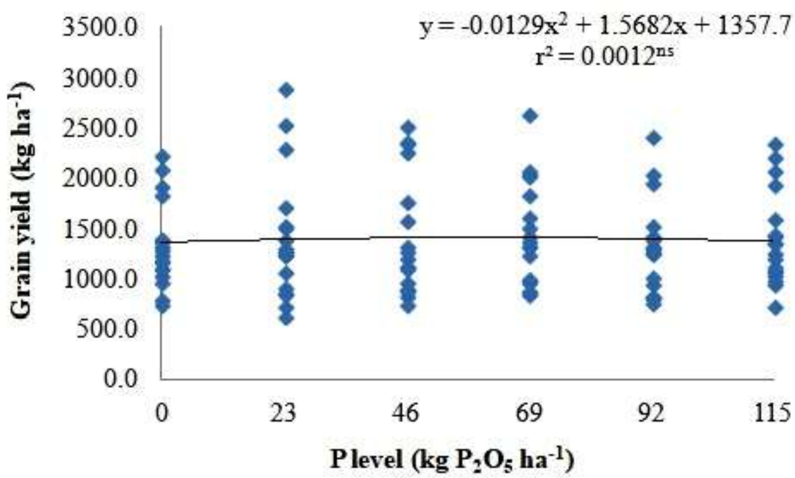

Figure 5. The P yield response curve of the grain yield data of six testing sites

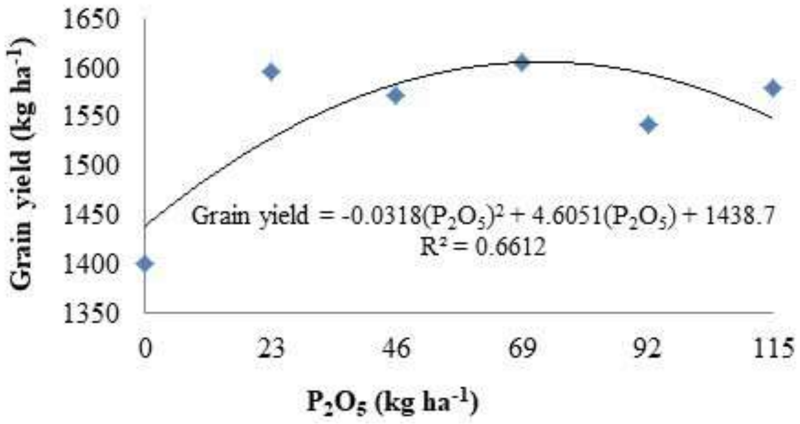

Figure 6. The P yield response curve of the mean grain yield data of treatments pooled over years and testing sites

Response of Tef to Sulfur Fertilizer

The effect of application of S on the yield of tef was found non-significant ($p>0.05$) in all the testing sites both in the first and second experimental years (Table 5) as compared to the zero S treated plot. The pooled analysis result of overall testing sites also revealed that the grain yield was not significantly affected by the application of S (Table 5).

Table 5. Response of tef (Grain yield (kg ha^{-1}) to S rates (in 2014, 2015 and combined over years)

Treatment* (kg S ha^{-1})	2014			2015			Combined
	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3	
-Ve control	594.1^{b}	837.3^{b}	724.4b^{c}	705.0^{b}	310.0^{d}	1065.0^{c}	713.0^{c}
0	1247.8^{a}	1091.7^{ab}	970.0^{a}	2192.5^{a}	1461.7^{abc}	2121.0^{a}	1514.1^{ab}
10	1036.3^{a}	1308.2a	967.8^{a}	2260.0^{a}	1545.0^{ab}	2265.0^{a}	1594.7^{a}
20	1177.3^{a}	1065.7^{ab}	979.8^{a}	2145.8^{a}	1638.3^{a}	2176.9^{a}	1530.6^{ab}
30	1224.8^{a}	1223.4^{ab}	1011.5^{a}	2416.7^{a}	1483.3^{abc}	2220.6^{a}	1596.7^{a}
40	1419.4^{a}	1111.8^{ab}	895.5^{ab}	2273.3^{a}	1325.0^{bc}	1630.0^{b}	1431.5^{b}
50	1366.2^{a}	1192.7^{ab}	696.8^{c}	2410.0^{a}	1553.3^{ab}	1754.1^{b}	1441.7^{ab}
+Ve control	1225.8^{a}	1134.1^{ab}	873.1^{abc}	2255.0^{a}	1230.0^{c}	2126.7^{a}	1474.1ab
CV (%)	17.0	17.7	11.7	15.8	12.1	9.3	14.5
SEM	203.2	198.5	104.2	336.3	159.6	179.5	205.4
Trt*Site	-	-	-	-	-	-	*

[*]Means within a column followed by the same letter are not significantly different at p = 0.05. ***** *= significance at 5% probability level.*

Conclusion and Recommendation

This study was conducted to investigate the yield response of tef to different levels of N, P and S fertilizers under balanced fertilization in three separate experiments. The result revealed that there was a significant ($P \leq 0.01$) and predictable yield response to application of N. The maximum yield was obtained at application of 138 and 115 kg N ha^{-1}. However, statistically equivalent ($P>0.05$) yield was recorded at 92 kg N ha^{-1}. Thus, the yield response curve showed that the grain yield reaches its maximum at 92 kg N ha^{-1} and declines beyond this rate. Tef yield response study to P fertilizer showed a significant response to P at 50% of the testing sites, while at 50% of the rest testing sites, tef yield response to application of P was not found significant ($p>0.05$). Although there was a significant treatment by site interaction effect on the yield, the average effect across all the testing sites and the yield response curve indicated that application of 23 kg P_2O_5 ha^{-1} was the agronomic optimum rate to maximize yield of tef. Application of S, however, was not found to have a significant effect on the yield of tef at all testing sites. Therefore, the application of S cannot be recommended for tef production in the district.

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