GSJ: Volume 10, Issue 3, March 2022, Online: ISSN 2320-9186
www.globalscientificjournal.com

Determination of Optimum Rate of Sulfur for Tef (*Eragrostis tef /Zucc./Trotter*) under Balanced Fertilization in Vertisol, East Shoa Zone, Oromia Regional State, Ethiopia

Assefa Gonfa*, Saba Fetene, and Sosena Amsalu

Debre Zeit Agricultural Research Center, Ethiopian Institute of Agricultural Research (EIAR)

*Corresponding author: A. Gonfa

E-mail Address: gonfa99@gmail.com

Abstract: Tef is an annual grass indigenous to Ethiopia. Tef seeds are small in size, and weight of 1000 seeds is 0.3 to 0.4g. *Currently, sulfur is emerging as limiting nutrient, especially in Vertisols. Therefore, the objective of this experiment was to determine optimum rate of sulfur for tef under balanced fertilization. A field experiment was conducted on-farm for two consecutive years (2015-2016) in Vertisol at Ada'a Dstrict. The experimental was laid out in a randomized complete block design (RCBD) with three replications per treatment. The experiment had 8 treatments (six rates of sulfur each with fixed rate of N, P_2O_5, K_2O, Zn, B, Control and recommended NP). Sulfur was applied at the rates of (0, 10,20,30,40, and 50) kg ha^{-1} and balanced fertilizer (N, P_2O_5, K_2O, Zn, B) at the rate of 92, 69, 90, 2, and 1 kg ha^{-1}, respectively. The ANOVA revealed that plant height (Plh) and grain yield (GY) were strongly significantly affected ($P<0.0001$) over control. However, number of tillers, above ground biomass (AGB) and straw yield (SY) were not significantly affected by sulfur rates application. The maximum and minimum tef grain yields were recorded at 30 kg S ha^{-1} and at negative control and the results were found being 1946 and 956 kg ha^{-1}, respectively. The treatment receiving 30 and 0 kg S ha^{-1} had shown 103.6% and 58.5% over control. The maximum net benefit was recorded at treatment that receiving 30 kg S ha^{-1} following by 20 kg S ha^{-1} and the net benefits were found being 69466.6 and 68318.9 ETB ha^{-1}. Treatments receiving 0, 30 kg S ha^{-1}, recommended NP (60 kg N ha^{-1}+10 kg P ha^{-1}), and 20 kg S ha^{-1} had recorded 92, 164, 168 and 2372% marginal rate of returns (MRR), respectively. Therefore, Based on MRR application of 20 kg S ha^{-1} under balanced fertilization could be recommended for the study site and areas having similar agro-ecology to the study site.*

Keywords: *Optimum, Refine, Balanced fertilization, Vertisol.*

1. Introduction

Tef is an annual grass indigenous to Ethiopia [15]. Tef is C4, self-pollinated and chasmogamous annual cereal crop[15]. Tef seeds are small in size, and weight of 1000 seeds is 0.3 to 0.4g. Tef produces massive fibrous root in early season growth [17]. In Ethiopia, tef is predominantly grown as cereal crop, not as forage crop [15]. However, the straw of tef is stored and used as a very important source of animal feed, especially during the dry season. Tef establishment is affected by different abiotic factors such as temperature, soil moisture, planting depth and soil texture. However, tef can be grown in a wide range of soil moisture conditions extending from highly drought to highly waterlogged soil, but the early season growth is weak until a very good root system is established [10]. Drought soil conditions reduce grain yield, especially if the stress occurs during the vegetative growth stage, and grain yield reduction of 40%-85.1% reported under greenhouse grown soil drought conditions [2] [18] [20]. Tef performs well at an altitude of 1800 - 2100 m a s l, annual rainfall of 750 - 850 mm, growing seasons rainfall of 450 - 550 mm and a temperature of 10˚C - 27˚C [14]. Moderately fertile clay and clay loam soils are ideal for tef. Tef can also withstand moderate water logged conditions [13]. Concerning on fertilizers application, there were different blanket fertilizer recommendations for various soil types of Ethiopia for tef cultivation. This is due to its cultivation in different agro-ecological zones and soil types, having different fertility status and nutrient content. Accordingly, different NP recommendation rates were set at 55:30, 30:40, and 40:35 kg N:P ha^{-1} for tef crop on Vertisols, Nitisols, and Camisoles across the country, respectively [14] and also 100:100 kg DAP: Urea ha^{-1} were set by the Ministry of ,Agriculture and Rural Development later [14]. . These blanket recommendations brought an increase in yield of improved cultivars ranging from 1700 to 2200 kg ha^{-1} [3]. Therefore, to overcome the problem that arose from the use of blanket fertilizer recommendation, determination of optimum rate of fertilizers for specific soil type and crop is required. The proper rates of plant nutrients can be determined by knowledge about the nutrient requirement of the crop and supplying power of the soil. Findings of the EthioSIS soil fertility mapping project in Ethiopia reported the deficiency of K, S, Zn, B and Cu in addition to N and P in major Ethiopian soils and thus recommended, customized and balanced fertilizers [6] [7]. Sulfur (S) is an essential plant nutrient required by all crops for optimum production. Chlorophyll synthesis also requires sulfur. As reported by [13] [11] [12] and [1] sulfur content in the soils they studied were found to be low and very low in Ethiopian soils. The symptom of sulfur deficiency also observed in Vertisols during evaluation of nutrient omission trial that was conducting on-farm. Different study was conducted on sulfur by different reseachers under different soil conditions and crop types. However, optimum rate of sulfur is not clearly identified. Therefore, the objectives of this experiment were to refine sulfur rate to obtain optimum rate under balanced fertilization for tef in Vertisols and to evaluate economic benefits. The concept of balanced fertilization paves the way for optimum plant nutrient supply to realize full yield potential of crop and to minimize soil fertility problem [19]

2. Materials and methods

2.1. Description of the study site

The experiment was conducted on-farm for two consecutive years, 2015 and 2016, in Vertisol at Ada'a District. The experimental area is found in agro-ecological zone that has altitude of 1897 m.a.s.l and located at $9^{0}6^{'}0^{''}$N and $37^{0}15^{'}0^{''}$ E. The experiment was laid out in a randomized complete block design (RCBD) with three replications and had 8 treatments (six rates of sulfur each with fixed rate of N, P_2O_5,K_2O,Zn, B, control (no fertilization) and recommended rate of NP(60N+10P) kg ha^{-1}. Sulfur was applied at the rates of (0, 10, 20, 30, 40 and 50) kg ha^{-1} and N,P_2O_5,K_2O,*Zn, and B* rated as 92, 69, 90, 2 and 1 kg ha^{-1}, respectively. Urea, triple super phosphate (TSP), potassium chloride, Zinc sulfate and Borax penta hydrate were the fertilizers used as sources of N,P_2O_5,K_2O,*Zn, B*, respectively. Calcium sulfate ($CaSO_4$) was a fertilizer used as sulfur source. The tef was sown nearly around 24 July in both experimental years into a well prepared soil in row planting system at a seed rate of 15 kg ha^{-1}. Each treatment was independently randomized in each block and received all necessary agronomic practices.

3. Results and discussion

3.1. Effect of sulfur fertilizer rates on tef height under balanced fertilization

The data were refined and subjected to the analysis of variance (ANOVA). In view of that, plant height was strongly significantly (P<0.0001) affected over control by fertilizer application (Table 1). However, there was no significant difference among treatments that received fertilizer application. The maximum and minimum plant height was recorded at 0 S (0S+*N*, P_2O_5, K_2O, *Zn*, *B*) and control (without fertilization) and the results were 125.4 and 101.1 cm, respectively (Table 1). This indicates that treatment 3 (nutrients applied in basal form with zero rate of sulfur (0S+*N*, P_2O_5, K_2O, *Zn*, *B*) has dominated the control by 24% in plant height. On the whole, there was no significant difference among treatments that received fertilizer application but they had shown significant difference over control. Therefore, application of optimum fertilizer rate is needed to improve crop productivity.

Table 1. *Effects of sulfur fertilizer on tef growth parameters*

Treatment	Plant height (cm)	number of Tillers
Control	101.1^b	5.32^b
RNP	120.3^a	5.72^{ab}
0S+N,P_2O_5,K_2O,Zn,B	125.4^a	5.95^{ab}
10S+ N,P_2O_5,O,K_2O,Zn,B	121.8^a	5.95^{ab}
20S+ N,P_2O_5,O,K_2O,Zn,B	123.3^a	6.45^a
30S+ N,P_2O_5,O,K_2O,Zn,B	124.6^a	6.27^{ab}
40S+ N,P_2O_5,O,K_2O,Zn,B	120.7^a	5.87^{ab}
50S+ N,P_2O_5,O,K_2O,Zn,B	120.4^a	6.00^{ab}
Mean	120.1	5.94
LSD	9.25	1.09
CV (%)	4.2	9.9
P-Value	***	*

3.2. Effects of sulfur fertilizer application on number of tillers under balanced fertilization

The number of tillers also significantly affected (p<0.05) by fertilizer application. For number of tillers the maximum result was recorded at treatment that received 20 kg S ha^{-1} and the minimum at control and the results were found being 6.45 and 5.32, respectively. The maximum result of number of tillers had shown significant difference only over control and there was no significant difference among treatments that received fertilizers.

3.3. Response of sulfur fertilizer rates to tef above ground biomass (AGB) under balanced fertilization

Similar to plant height and number of tillers, the above ground biomass (AGB), grain yield (GY) and straw yield (SY), were subjected to analysis of variance (ANOVA). The ANOVA revealed that the above ground biomass had significantly influenced (P<0.05) by sulfur rates application under balanced fertilization. Accordingly, 30 and 50 kg S ha^{-1} had shown significant difference over control. The maximum and minimum results were recorded at 30 kg S ha^{-1} and at control and the results were found being 11972 and 9232 kg/ha, respectively (Table 2). This shows a dominance of 29.7% over control. In general, all treatments that received fertilizer application had no significant difference among themselves but over negative control.

Table 2. *Effect of sulfur fertilizer rates on tef grain yield under balanced fertilization*

Treatment	AGB (kg/ha)	GY(kg/ha)	SY(kg/ha)
Control	9232^b	956^c	8275
RNP	10111^{ab}	1372^b	8739
0S+ N,P_2O_5, K_2O,Zn,B	10398^{ab}	1515^b	8883
10S+ N,P_2O_5, K_2O,Zn,B	9929^{ab}	1425^b	8504
20S+ N,P_2O_5, K_2O,Zn,B	11028^{ab}	1941^a	9088
30S+ N,P_2O_5,K_2O,Zn,B	11972^a	1946^a	10027
40S+ N,P_2O_5,K_2O,Zn,B	11046^{ab}	1521^b	9526
50S+ N,P_2O_5,K_2O,Zn,B	11556^a	1475^b	10080
Mean	10659	1559	9140
LSD (0.05)	2123	259	2138
CV (%)	17.0	14.5	20.0
P-Value	*	****	NS

Means with the same letters in the same column are not significantly different at α=0.05, AGB=above ground biomass, GY= grain yield, SY= straw yield

3.4. Effect of sulfur fertilizer rates on grain yield of tef under balanced fertilization

The ANOVA revealed that the grain yield of treatments that received fertilizer application had shown strong significant difference (P<0.0001) over control. From treatments that received fertilizer the treatments that received 20 and 30 kg S ha^{-1} had shown significant difference over other treatments that received fertilizer application. However, there was no significant difference among the two treatments which recorded maximum grain yields. The maximum and minimum grain yields were recorded at 30 kg S ha^{-1} and control and the results were 1946 and 956 kg ha^{-1}, respectively. This shows a dominance of grain yield obtained at 30 kg S ha^{-1} by 103.6% over that of control. Tamene et al. [19] reported that the maximum grain yield of maize was obtained at 10 kg S ha^{-1} under balanced fertilization. The grain yield obtained at recommended NP (RNP) fertilizer application (1372 kg ha^{-1}) was dominated by the highest result by 41.8 percent. The decrease in grain yield was occurred as rates of sulfur increased. This might be due to lodging. In general, the highest grain yield (1946 kg ha^{-1}) overwhelmed the national average yield (1740 kg ha^{-1}) by 11.8 percent [5]. This might be due to the combined effect of nutrients like N, P_2O_5, S, K_2O, Zn and B which might be enhanced growth and productivity of the crop.

3.5. Effects of sulfur application on tef straw under balanced fertilization

The ANOVA revealed that the straw yield was not significantly influenced (P>0.05) by sulfur application. Accordingly, there was no significant difference among the treatments statistically but mathematically. Mathematically, the maximum result was recorded at treatment that received 50 kg S ha^{-1} and the minimum at control. The results were 10080 and 8275 kg ha^{-1}, respectively. This shows a dominance of maximum straw yield over that of control by 21.8 percent. In general, the experiment had given a clue about optimum sulfur rate that will be used under balanced fertilization for tef productivity. The finding coincides to that of [16] that above ground biomass and the grain yield significantly affected by sulfur fertilizer application in Vertisol under balanced fertilization.

An attempt has been made to fit the yield data to the quadratic equation $y = a + bx + cx^2$. The equation thus obtained was $Y=1408+27.95x+-0.541x^2$ (Figure 1, below). From the equation, an optimum sulfur rate that has maximized yield has been computed following the procedure, as outlined by Gomez and Gomez [9]. Rate of sulfur that maximizes yield: ***By= - b/2c,*** Where **b** and **c** were the estimates of the regression coefficient. The *By* value was estimated as 25.8 kg ha^{-1} based on regression coefficient. The rate of sulfur that maximizes the yield: 25.8 kg ha^{-1}.

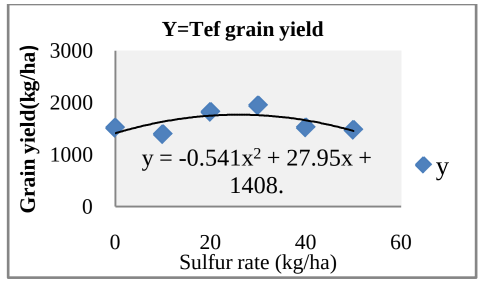

Figure 1. Relationship between grain yield and sulfur rates

4. Economic Analysis
4.1. Dominant Analysis

Economic analysis was conducted to investigate the economic feasibility of the treatments, i.e. partial budget, dominance and marginal rate of returns were performed [4]. The mean grain and straw yields were adjusted downwards by 10% to reflect the difference between the experimental plot yield and the yield farmers could expect from the treatment. The maximum net benefit was recorded by treatment 6 (30S+N, K_2O, P_2O_5, Zn, B) and following by treatment 5 (20S+N, K_2O, P_2O_5, Zn, B) as 69466.6 ETB ha^{-1} and 68318.9 ETB ha^{-1}, respectively. The net benefits increment was found inconsistent with respect to cost that vary. Accordingly, the three treatments (4, 7 and 8) had dominated by nearby proceeding treatments net benefits that invested in lower cost that vary. The maximum marginal rates of return (MRR %) was recorded by treatment that receiving 20 kg S ha^{-1} with 2372% MRR. The next maximum MRR% was recorded by recommended N and P and 186% MRR was recorded by it. According to CIMMYT [4], the minimum MRR% acceptable by farmers falls in the range of 50-100 %. However, the amounts of MRR% of three treatments were found above the range of minimum marginal rate of returns and only one treatment found falls within the range given by CIMMYT as minimum marginal rates of returns (50-100%) range. However, the MRR of 100% was suggested as realistic [18] Hence, to make recommendations from marginal analysis, the MRR was taken to be 100%. Based on the MRR%, treatment 5 (20S+N, P_2O_5, K_2O, Zn, B) is well recommended.

Table 3. Economic benefits analysis for tef that affected by different rates of sulfur under balanced fertilization

Treatments	Cost that vary (ETB ha^{-1})	Gross Benefit (ETB ha^{-1})	Net Benefits (ETB ha^{-1})	Marginal net benefits (ETB/ha)	Marginal costs that vary (ETB/ha)	MRR (%)
Control	0	45009.0	45009.0	-	-	-
RNP(60+10)kg/ha	4874	58948.2	54074.2	9065.2	4874	186
0S+ N,P_2O_5, K_2O,Zn,B	7781	63711.9	55930.9	1856.2	2907	92
10S+ N,P_2O_5, K_2O,Zn,B	8481	60194.7	51713.7	-	-	D
20S+ N,P_2O_5, K_2O,Zn,B	9181	77499.9	68318.9	16605.2	700	2372
30S+ N,P_2O_5,K_2O,Zn,B	9881	79347.6	69466.6	1147.7	700	164
40S+ N,P_2O_5,K_2O,Zn,B	10581	65058.3	54477.3	-	-	D
50S+ N,P_2O_5,K_2O,Zn,B	11281	64606.5	53325.5	-	-	D

ETB=Ethiopian birr, D= dominated, MRR= Marginal Rate of Return

4.2. Relationships between net benefit and cost that vary

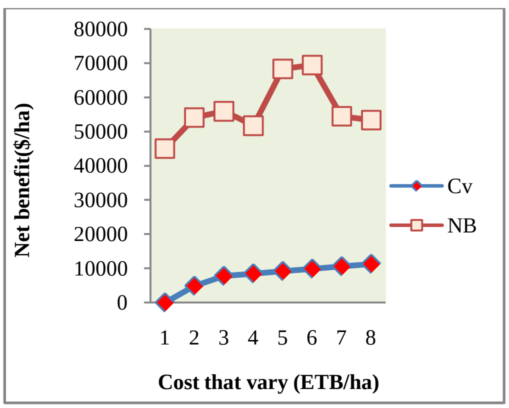

Figure 2. Trend of net benefit and cost that vary

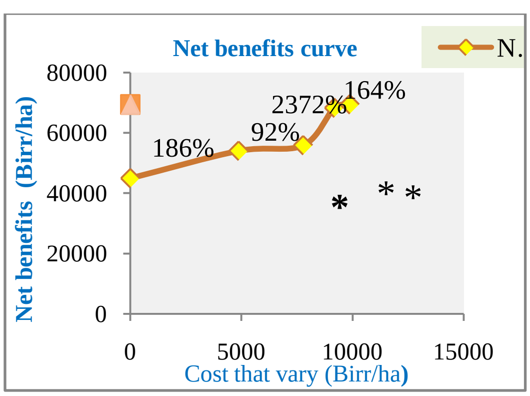

Figure 3. Net benefit curve

The relationship between net benefits and cost that vary were not found smooth. The net benefits formed zigzag line when compared with the costs that vary. The net benefit curve showed smooth slope between treatments 1 (control) and RNP with 186% MRR and then decreased to 92% MRR. However, there was steeper slope between treatments 3 and 5 (0S+ N,P_2O_5,K_2O,Zn,B and 20S+N,P_2O_5,K_2O,Zn,B) with maximum MRR, 2372% and then formed smooth slope between treatment 5 and 6 (20S+N,P_2O_5,K_2O,Zn,B and 30S+NPKZnB) with 164% MRR. In general, 20 kg S ha^{-1} has shown higher MRR % over all. Therefore, 20 kg ha^{-1} could be recommended under balanced fertilization in experimental area and other similar agro-ecology.

5. Conclusion and recommendation

Sulfur (S) is an essential plant nutrient required by all crops for optimum crop production. Cereal crops like wheat and tef are showing symptoms of sulfur deficiency in Vertisols. However, application of sulfur without other essential nutrients is not sufficient for optimum crop productivity. As a result refining of sulfur rates for optimum plant growth under balanced fertilization was required. As observed from the results, OS+N, P_2O_5, K_2O, Zn, B, was found beating the control (without fertilizer). However, superior yields have been recorded with different rates of sulfur in the presence of balanced fertilization even if gradually decreased as rates of sulfur going increased.

Plant height and grain yield had shown strongly significant difference over control. The finding indicates that mathematically 30 kg S/ha gave sound grain yield over all treatments in the presence of balanced fertilization. However, 20 kg S ha^{-1} with balanced fertilization has recorded maximum marginal rate of return and also statistically had no difference from grain yield recorded with 30 kg S/ha. Therefore, 20 kg S ha^{-1} under balanced fertilization could be recommended with additional validation in areas having similar agro-ecologies with experimental site.

References

1. Admas, H., Gebrekidan, H., Bedadi, B. and Adgo, E. (2015). Effects of Organic Andx Inorganic Fertilizers on yield and yield components of Maize at Wujiraba Watershed, North western Highlands of Ethiopia. American Journal of Plant Nutrition and Fertilization Technology, 5, 1-15. https://dx.doi.org/10.3923/ajpnft.2015.1.15
2. Ayele, M. 1993. Use of excised-leaf water content in breeding tef [(*Eragrostis tef* (Zucc.)Trotter] for moisture stressed areas. Acta Agron. 42:261-265
3. Bellete, T. (2014) Fertility Mapping of Soils of Abay-Chomen District, Western Oromia, Ethiopia. MSc Thesis, Haramaya University, Haramaya..
4. CIMMYT (International Maize and Wheat Improvement Center) (1988) An Economic Training Manual: From Agronomic Data Recordation. International Maize and Wheat Improvement Center, El Batán, 79 p.
5. CSA (Central Statistical Agency), (2017) Agricultural SampleSurvey 2016/2017 Agricultural Sample Survey. Agricultural sample survey, report on area and production of major crops, Addis Ababa, Ethiopia.
6. Ethio SIS (Ethiopia Soil Information System) (2014) Soil Fertility Status and Fertilizer Recommendation Atlas for Tigray Regional State, Ethiopia. Ethiopia Soil Information System, Addis Ababa.
7. Ethio SIS (Ethiopia Soil Information System) (2015) http://w.w.w.ata.gov.et/
8. Getachew Agegnehu , Angaw Tsigie and Agajie Tesfaye, 2012. Evaluation of crop residue retention, compost and inorganic fertilizer application on barley productivity and soil chemical properties in the central Ethiopia highland. *Ethiopia. J. Agric. Sci.* 22: 45-61.
9. Gomez, K.A. and Gomez, A.A, (1984). *Statistical Procedures for Agricultural Research. 2nd ed.* John Wiley and Sons, New York, USA.P. 680.
10. Hunter, M., P. Barney, T. Kilcer, J. Cherney, J. Lawrence, and Q. Ketterings. 2007. Teff as emergency forage. Cornell University extension, Agronmy Fact Sheet Series, FS 24.Ithaca,
11. Laekemariam, F., 2015. Soil Spatial Variability Analysis, Fertility Mapping and Soil Plant Nutrient Relations in Wolaita Zone, Southern Ethiopia. PhD Dissertation. Graduate School, Haramaya University, Harar.
12. Lemenih, M. (2004) Effects of Land Use Change on Soil Quality and Native Flora Degradation and Restoration in the Highlands of Ethiopia. Implication for Sustainable Land Management. A PhD Thesis Submitted to University of Swedish Agricultural Science, Uppsala.
13. National Soil Service (1994) Training Materials on Soils for Use by Development Personnel. Watershed Development and Land Use Department MONRDEP, Addis Ababa.
14. Seyfu K., 1993. Tef [*Eragrostistef* (*Zucc*.) Trotter].Breeding, Genetic Resources, Agronomy, Utilization and Role in Ethiopian Agriculture. Institute of Agricultural Research, Addis Ababa, Ethiopia.
15. Seyfu K., 1997. [Eragrostis tef (Zucc.) Trotter]. Promoting the Conservation and Use of Underutilized and Neglected Crops. Vol. 12. Institute of Plant Genetics and Crop Plant Research, Gatersleben/International Plant Genetic Resources Institute, Rome.
16. Shawl A. Beza S. and Kenzemed K., 2020. Response of Bread Wheat (*Triticum Aestivum* L.) to Sulfur Fertilizer Rate under Balanced Fertilization at Basona Warena District of North Shewa Zone of Amhara Region,Ethiopia. https://doi.org/10.1080/00103624.2020.1845361
17. Stallknecht, G.F., K.M. Gilbertson, and J.L. Eckhoff. 1993. Teff: Food crop for humans and animals. p. 231-234. In: J. Janick and J.E. Simon (eds.), New Crops. Wiley,New York.
18. Takele, A. 1997. Genotypic variability in dry matter production, partioning and grain yield of tef (Eragrostis tef (Zucc.) Trotter) under moisture deficit. SINET. Ethiop. J.Sci. 20:177-188.
19. Tamene D, Anbessa B, Legesse TA, Dereje G., 2018. Refining Fertilizer Rate Recommendation for Maize Production Systems in Assosa, North Western Ethiopia. *Adv Tech Biol Med* 6: 253. doi:10.4172/2379-1764.1000253
20. Teferra T, Tefera H, Simane B, Tuinstra M., 2000. The influence of moisture stress on growth, leaf water loss rate and phonological development of tef (Eragrostis tef).Trop. Sci. 40:100-107.