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

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Abstract: The fertilizer requirement of tef varies from agro-ecology to agro-ecology and from soil to soil. Therefore, the objective of this study was to refine optimum phosphorus rate for tef under balanced fertilization. The experiment was conducted on-farm during main cropping season for two consecutive years (2015-2016) in Vertisol at Ada'a District. The experiment had 8 treatments (six phosphorus rates each with fixed amount of N, K_2O, S, Zn and B, negative control (without fertilizer), and recommended NP (60 N+10 P) kg ha^{-1}). Phosphorus was applied at the rates of 0, 23, 46, 69, 92 and 115 kg P_2O_5 ha^{-1} using TSP (triple super phosphate) as a source of it. Nitrogen, K_2O, S, Zn and B were applied at the rate of 92, 90, 30, 2 and 1 kg ha^{-1} from urea, potassium chloride, calcium sulfate, zinc sulfate and borax penta hydrate fertilizers, respectively. The experiment was laid out in a randomized complete block design (RCBD) with triple replication of each treatment. The ANOVA revealed that plant height and number of tillers were highly significantly affected ($P<0.05$) with phosphorus application rates. The above ground biomass (AGB), grain yield (GY) and straw yield (SY) which received phosphorus rates strongly significantly affected ($P<0.001$) over control. The maximum grain yield was recorded at 69 kg P_2O_5 ha^{-1} (30 kg P ha^{-1}) following by 46 kg P_2O_5 ha^{-1} (20 kg P $ha^{-1)}$ and the results were found being 1719 and 1607 kg ha^{-1}, respectively. Similarly, the maximum net benefits was recorded at 69 kg P_2O_5 ha^{-1} (30 kg P ha^{-1}) and then at 46 kg P_2O_5 ha^{-1} (20 kg P ha^{-1}) and the amounts were found being 56035.1 and 54744.4 ETB ha^{-1}, respectively. However, the maximum marginal rate of return was recorded at 46 kg P_2O_5 ha^{-1} (20 kg P ha^{-1}) and then by recommended NP with MRR 1329.5% and 306.8%, respectively. Therefore, 46 kg P_2O_5 ha^{-1} (20 kg P ha^{-1}) could be recommended for the study site and areas having similar agro-ecology with the study area.

Keywords: Optimum, Phosphorus Rates, Refining, Balanced/Blended Fertilizer, Tef, Vertisols

1. Introduction

Tef [*Eragrostistef* (Zucc.*)*Trotter] is a small cereal grain indigenous to Ethiopia. Ethiopia is the center of origin and diversity of tef [18]. Tef belongs to the grass family Poaceae and genus [14]. Tef is a daily staple food for most Ethiopian people [1]. Tef covers the largest agricultural area of the country next to maize but its productivity is low [18]. In Ethiopia, currently, tef is cultivated on area of about 3.02 million hectares. The average national yield of tef is about 1.740 tons per ha (1740 kg ha^{-1}) [5]. This indicates the low productivity of the tef. Some of the factors contributing to the low yield of tef are low soil fertility and suboptimal use of fertilizers, weeds, and erratic rainfall distribution and drought particularly in the low altitudes areas, lack of high yielding cultivars, lodging and water-logging [6]. Concerning on soil fertility, soil fertility map was made by agricultural transformation agency (ATA) for regions found in Ethiopia. According to the soil fertility map made over 150 districts, Ethiopian soil lacks about seven nutrients (N, P, K, S, Cu, Zn and B) [7]. Soils in the highlands of Ethiopia usually have low levels of essential plant nutrients and organic matter content [9]. Accordingly, the study site has found having lack of N, P, K, S, Zn and B. In Ethiopia, smallholder farmers generally apply low amounts of mineral fertilizers to crops [12, 10, 3]. In Ethiopia, di-ammonium phosphate (DAP) and urea have been the only chemical fertilizers used for crop production. Earlier studies recognized that nitrogen and phosphorus are the major limiting nutrients of Ethiopian soils [2]. However, plant growth and crop production require adequate supply and balanced amounts of all nutrients, but the use of only urea and DAP have totally neglected the use of micronutrients [11]. Therefore, the study was suggested to refine optimum phosphorus rate under blended/balanced fertilization.

The drive for higher agricultural production without use of balanced fertilizers created problems of soil fertility exhaustion and plant nutrient imbalances [13]. Most research work so far focused on nitrogen and phosphorus (NP) requirements of crops and, hence, limited information is available on various sources of fertilizers like S, Zn, and B. Farmers in most parts of the country, in particular, in Ada'a district, have limited information on the impact of phosphorus fertilizers rates under balanced fertilization. In Ethiopia, about 70% of the soils are deficient in phosphorus [17]. This low availability of phosphorus has been demonstrated to be a major constraint to cereal production due to unbalanced nutrient supply cultivation. Thus, there is a need to develop site specific phosphorus rate recommendation under balanced fertilization to increase production and productivity of tef. Therefore, the objectives of this study were to refine phosphorus rates to obtain optimum rate for tef under balanced fertilization and to evaluate economic benefits of different phosphorus rates under balanced fertilization.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted on-farm for two consecutive years, 2015 and 2016 in Vertisol at Ada'a District, East Shoa Zone, Oromia Regional State, Ethiopia. Ada'a district is geographically located at 9°6'0"N, and 37°15'0" E with 1897 meters above sea level (m.a.s.l). The climate of the study area is temperate with average minimum and maximum temperature of 8 and 27°C and average annual rainfall 892 mm

2.2. Treatments and Experimental Design

The experiment was laid out in a randomized complete block design (RCBD) with three replications of each treatment. The treatments were six phosphorus rates each with fixed amount of N, K_2O, S, Zn and B, control (no fertilizer), and recommended rate of NP (60 N and 10P) kg ha^{-1}. The source of phosphorus was Triple super phosphate (TSP). The levels of phosphorus were 0, 23, 46, 69, 92 and 115 kg P_2O_5 ha^{-1}. Nitrogen, K_2O, S, Zn and B were applied as balanced fertilizer in basal form at the rate of 92, 90, 30, 2 and 1 kg ha^{-1}, respectively. The sources of N, K_2O, S, Zn and B were urea, potassium chloride, calcium sulfate, zinc sulfate and borax penta hydrate, respectively. 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}. The tef variety used for the experiment was Quncho (DZ-cr-385, LIR 355). All treatments were received similar agronomic management or cultural practices.

2.3. Statistical Analysis

All data were analyzed using Statistical Analysis System (SAS), Version 9.0, following appropriate RCBD procedures as stated by Gomez and Gomez [8]. The analysis was conducted to test the significance levels of variables, and Least Significant Difference (LSD) was used to separate treatment means at $\alpha = 0.05$.

3. Results and Discussion

Growth parameters and yield and yield components were subjected to analysis of variance (ANOVA). The ANOVA results revealed that both, growth parameters and yield and yield components, had strongly significantly affected by phosphorus fertilizer rates applications.

3.1. Effect of Phosphorus Fertilizer Rates on Tef Growth Parameters Under Balanced Fertilization

The results revealed that plant height was strongly significantly ($P<0.001$) influenced by phosphorus fertilizer rates application over control. However, there was no significant difference among P rates as well as among P rates and recommended NP. The maximum and minimum results were recorded at treatment receiving 92 kg P_2O_5 ha^{-1} and control for plant height and the results were found being 125.6 and 107.5 cm, respectively (Table 1). Balanced fertilizer without phosphorus application (0P+ N, K_2O, S, Zn, B) had shown significant difference over control by 11% in plant height. The maximum plant height recorded at 92 kg P_2O_5 ha^{-1} had dominated the control by 16.8% and this showed a difference of 5.8% from nil (zero) rate of P fertilizer application with balanced fertilizer.

Table 1. *Effect of different rates of phosphorus fertilizer on tef height and No of tillers under balanced fertilization.*

Treatment	Plant height (cm)	Tillers
Control	107.5b	3.05d
RNP (60N+10 P) kg/ha	122.1a	5.28a
$0P_2O_5$+N K_2O S Zn B	119.4a	5.02ab
$23P_2O_5$+N K_2O S Zn B	123.4a	5.22a
$46P_2O_5$+N K_2O S Zn B	123.6a	4.33c
$69P_2O_5$+N K_2O S Zn B	123.9a	4.52bc
$92P_2O_5$+N K_2O S Zn B	125.6a	5.32a
$115P_2O_5$+N K_2O S Zn B	121.7a	5.00ab
Means	120.9	4.71
LSD	8.72	0.58
CV (%)	6.2	10.5
P-value (5%)	**	***

RNP= recommended nitrogen and phosphorus.

3.2. Effect of Phosphorus Rates on Number of Tillers of Tef Under Balanced Fertilization

The ANOVA revealed that application of fertilizers had shown strongly significant influence (P<0.0001) over control in number of tillers. For number tillers, the maximum result was recorded at treatment 7 (92 kg P_2O_5 ha^{-1}) and the minimum at control and the results were 5.32 and 3.05 in average, respectively (Table 1). This shows a dominance of 227% over control. The numbers of tillers have direct relationships with the yield. However, in this study, the maximum grain yield had recorded at treatments having medium number of tillers (46 and 69) kg P_2O_5 ha^{-1}. This may be due to having most fertile tillers relative to other treatments that having high number of tillers but medium grain yields (Table 1). Recommended NP also recorded maximum number of tillers next to treatment that receiving 92 kg P_2O_5 ha^{-1} and the result was 5.28 in number.

In a similar manner to growth parameters the grain yield and yield components were subjected to analysis of variance (ANOVA). The results revealed that the grain yield and yield components were strongly significantly (P<0.0001) influenced by phosphorus fertilizer rates application.

3.3. Response of Phosphorus Fertilizer Rates for Tef Under Balanced Fertilization

The above ground biomass that received phosphorus fertilizer rates had shown strongly significant difference (P<0.0001) over control. The maximum result was recorded at treatment that receiving 46 kg P_2O_5 ha^{-1} and the minimum at control (without fertilization) and the results were 13213 and 8232 kg ha^{-1}, respectively (Table 2). The maximum results were recorded at three treatments which receiving 46, 69 and 92 kg P_2O_5 ha^{-1} with various mathematical differences. However, there was no significant difference among treatments that receiving 46, 69 and 92 kg P_2O_5 ha^{-1} under balanced/blended fertilization. In general, the AGB was increased from 0-46 kg P_2O_5 ha^{-1} and then decreased as rates P increased.

Table 2. *Effect of phosphorus fertilizer rates on Tef under balanced fertilization.*

Treatment	AGB ($kgha^{-1}$)	GY ($kgha^{-1}$)	SY ($kgha^{-1}$)
Control	8232d	940d	7328e
RNP (60N+10P) kg/ha	9778cd	1241c	8537de
$0P_2O_5$+N K_2O S Zn B	10398bc	1394bc	9005cde
$23P_2O_5$+N K_2O S Zn B	10985bc	1356bc	9629bcd
$46P_2O_5$+N K_2O S Zn B	13213a	1607ab	11606a
$69P_2O_5$+N K_2O S Zn B	12806a	1716a	11090ab
$92P_2O_5$+N K_2O S Zn B	11713ab	1279c	10434abc
$115P_2O_5$+N K_2O S Zn B	10944bc	1224c	9721bcd
Mean	11009	1340	9669
LSD (0.05)	1762	268	1796
CV (%)	13.7	17.1	15.9
P-Value	****	****	****

AGB=above ground biomass, GY= grain yield, SY= straw yield.

3.4. Effect of Phosphorus Fertilizer Rates on Grain Yield Under Balanced Fertilization

The results revealed that the grain yield was strongly significantly (P<0.0001) influenced by application of fertilizer rates under balanced fertilization. The maximum grain yield (GY) was recorded at treatment that receiving 69 kg P_2O_5 ha^{-1} (Table 2). However, there was no significant statistical difference from the result that recorded at treatment that receiving 46 kg P_2O_5 ha^{-1}. The results of the two treatments that receiving 69 and 46 kg P_2O_5 ha^{-1} were 1716 and 1607 kg ha^{-1}, respectively (Table 2). The minimum result was recorded at negative control (without fertilization) and the result was found being 940 kg ha^{-1}. The maximum result (1716 kg ha^{-1}) was dominated the minimum (904 kg ha^{-1}) by 82.6 percent. Recommended NP (1242 kg ha^{-1}) also dominated the grain yield that obtained at control (940 kg ha^{-1}) by 32.0 percent. As reported by [15] application of phosphorus rates under balanced fertilization increased the maize grain yield significantly. The difference is that the maximum maize grain yield obtained at 46 kg P_2O_5 ha^{-1}. In general, the fertilizer rates did not show consistent grain increment. The grain yield going decreased as rates of phosphorus going increased. Accordingly, the two maximum P rates (92 and 115) kg P_2O_5 ha^{-1} were recorded low grain yields relative to other treatments that received fertilizer. This may be due to occurrence of lodging at high P rates. As a whole, all phosphorus fertilizer rates under balanced fertilization had dominated the control in scoring better grain yield. They also dominated the recommended NP except treatment 8 that receiving 115 kg P ha^{-1}.

3.5. Effect of Phosphorus Fertilizer Rates on Tef Straw Yield Under Balanced Fertilization

In a similar manner to the above ground biomass (AGB) and grain yield (GY), the straw yield was significantly (P<0.0001) affected by phosphorus rates application under balanced fertilization. The maximum result was recorded at 46 kg P_2O_5 ha^{-1} and the result was found being 11606 kg/ha (Table 2). However, there were no significant differences among the three straw results which recorded at 46, 69 and 92 kg P_2O_5 ha^{-1}. The maximum and minimum straw yields were recorded at 46 kg P_2O_5 ha^{-1} and negative control (without fertilization) and the results were found being 11606 and 7329 kg ha^{-1}, respectively. Accordingly, the maximum straw yield was dominated the straw yield that obtained at control by 57.8 percent. The recommended NP also recorded low straw yield when compared to treatments that received phosphorus fertilizer rates under balanced fertilization. In general, most of phosphorus fertilizer rates had shown significant effect over control under balanced fertilization.

However, there was no significant statistical difference among the treatments that receiving 69 and 46 kg P_2O_5 ha^{-1} both in tef grain yield and yield components. As a result, 46 kg P_2O_5 ha^{-1} could be recommendable due to economic aspect.

An attempt has been made to fit the yield data to the quadratic equation y = a + bx + cx^2. The equation thus obtained was $Y=1329+9.805x-0.095x^2$ (Figure 1 below). From the equation, an optimum P rate that has maximized the yield has been computed following the procedure, as out lined by Gomez and Gomez [8]. Rate of phosphorus that maximizes yield: *By= - b/2c,* Where b and c were the estimates of the regression coefficient. The *By* value was estimated as 51.9 kg P ha^{-1} based on regression coefficient.

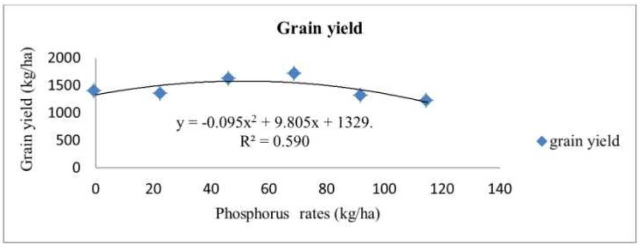

Figure 1. *Graph of tef grain yield vs P rates under balanced fertilization.*

4. Economic Analysis

4.1. Dominance Analysis

Economic analysis was carried out to investigate the economic feasibility of the treatments (fertilizer rates) using economic training manual of CIMMYT [4]. The analysis showed that the maximum net benefit (56035.1 ETB ha^{-1}) recorded at 69 kg P_2O_5 ha^{-1} application under balanced fertilization. The next maximum net benefit was recorded at 46 kg P_2O_5 ha^{-1} application under balanced fertilization. Concerning on marginal rate of returns, the maximum MRR% recorded at 46 kg P_2O_5 ha^{-1} and the result found being 1329.5 (Table 3). This was the largest marginal rate of return (MRR %). The next maximum MRR % was recorded at RNP and the result found being 306.8. Therefore, based on MRR% 46 kg P_2O_5 ha^{-1} could be recommended to the study site and areas having similar agro-ecology to that of experimental site.

Table 3. *Economic analysis P fertilizer rates application on tef under balanced fertilization.*

Treatment	Gross net benefits (ETB ha^{-1})	Total cost that vary (ETB ha^{-1})	Total net benefit (ETB ha^{-1})	Marginal net benefits (ETB/ha)	Marginal costs that vary (ETB ha^{-1})	MRR (%)
Control	38570.4	0	38570.4	-	-	-
RNP	48873.6	2533	46340.6	7770.2	2533	306.8
$0P_2O_5$+N K_2O S Zn B	53847.0	8088	45759.0	-	-	D
$23P_2O_5$+N K_2O S Zn B	53944.2	8812	45132.3	-	-	D
$46P_2O_5$+N K_2O S Zn B	64279.8	9535	54744.4	9612.1	723	1329.5
$69P_2O_5$+N K_2O S Zn B	66294.0	10259	56035.1	1290.7	724	178.3
$92P_2O_5$+N K_2O S Zn B	53314.2	10982	42331.8	-	-	D
$115P_2O_5$+N K_2O S Zn B	50545.8	11706	38839.9	-	-	D

D= Dominated, ETB= Ethiopian Birr, RNP= Recommended N and P.

4.2. Net Benefits Versus Costs That Vary

The relationships between net benefits and cost that vary were seen using the graph. However, the net benefits did not linearly relate with costs that vary. Because, treatments 4, 7 and 8 had recorded low net benefits (Table 3).

The net benefits curve was also seen for non dominated treatments. From treatment 1 (control) to treatment 2 (Rec.NP) the marginal rate of return found went steeper.

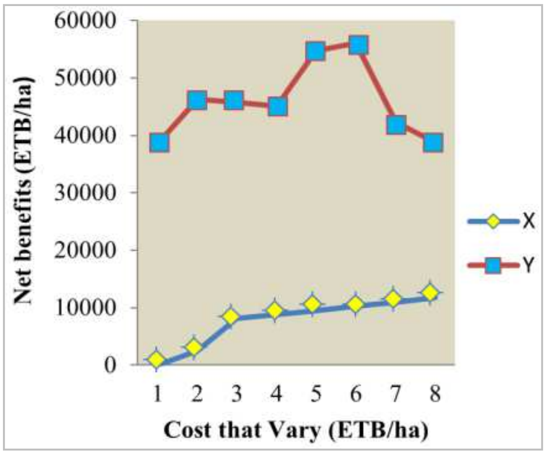

Figure 2. *Relationships between net benefits and cost that varies.*

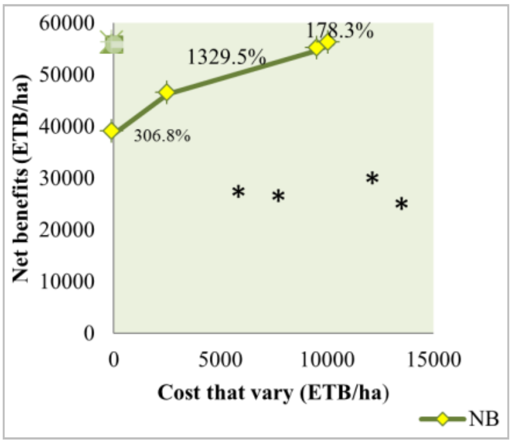

Figure 3. *Net benefit curve of phosphorus rates on tef under balanced fertilization.*

In the same manner, the marginal rate of return highly increased from treatment 2 (Rec.NP) to treatment 5 (46 kg P_2O_5 ha^{-1}) and finally slowly increased from treatment 5 (46 kg P_2O_5 ha^{-1}) to treatment 6 (69 kg P_2O_5 ha^{-1}). Treatments 3, 4, 7 and 8 had been dominated.

5. Conclusion and Recommendation

The refining of phosphorus fertilizer rates under balanced fertilization was conducted in the presence of control (without fertilizer) and recommended NP. The highest results were recorded at 69 kg P_2O_5 ha^{-1} (30 kg P ha^{-1}) and then at 46 kg P_2O_5 ha^{-1} (20 kg P ha^{-1}) in the presence of balanced fertilizers with 1716 and 1607 kg ha^{-1} grain yield, respectively. However, there was no significant difference among these two treatments. The marginal rates of returns were analyzed to identify the treatment that shown better economic benefit. Accordingly, the highest marginal rate of return (MRR %) was recorded at 46 kg P_2O_5 ha^{-1} (20 kg P ha^{-1}) with 1329.5% and then by recommended NP with 306.8%. The least MRR% was recorded at 69 kg P_2O_5 ha^{-1} (30 kg P ha^{-1}). Therefore, application of 46 kg P_2O_5 ha^{-1} (20 kg P ha^{-1}) could be recommended under balanced fertilization for the study site and areas having similar agro-ecologies with experimental site.

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