Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.7, No.19, 2017
www.iiste.org

Phosphorus Critical Level and Optimum Nitrogen Rate Determination on Teff for Sustainable Soil Fertility Management and Economical Teff Production at Lume Area of Oromia Region, Ethiopia

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Abstract
Nutrient management is fundamental activity of the grower for crop production and productivity increments on different soil types. Accordingly, soil test based teff response P fertilizer calibration study was made from 2010-2012 at Lume district on eutric vertisol, because soil nutrient calibration study is pertinent to increase the use efficiency of inorganic fertilizer like DAP and Urea. The objective of the experiment was to determine economically optimum N, and to determine Phosphorus critical (Pc) and Phosphorus requirement factor for teff at Lume district. The experiment were contained factorial combination of four levels of N (0, 46, 92 and 138 Kg ha-1) and P (0, 23, 46 and 92 Kg ha-1) chemical fertilizer laid out in randomized complete block design with two replications that had $40m^2$ plot area for each. After 21 days intensive soil samples were collected from each plot for the determination of available P in ppm. Plant height, biomass and grain yield data were collected from $9m^2$. The collected data were subjected to two way factorial analysis of variance (ANOVA) using the General Linear Model (GLM) procedures of SAS (SAS, 2001). Comparison of treatment means was performed using Fisher's Least Significant Difference test at $P < 0.05$ probability level. The application of N indicated that significant difference between plant height, biomass and grain yield teff. However the application of P was not significant on plant height, straw yield and grain yield at Lume. The interaction effect of N and P application was not significant to grain yield, plant height and straw yield correlation. Furthermore, the study was revealed that phosphorus critical (Pc) point for teff was **13**, and phosphorus requirement factor was also **3.65**. In addition, a partial budget analysis made using the annual average teff grains prices showed **46 kg** ha^{-1} gave a marginal rate of return of **271.95%**, which are above acceptable minimum rate of return.
Keywords: Calibration, P- critical, P- requirement factor, partial budget, Acceptable minimum rate of return

INTRODUCTION

In Ethiopia, currently growth in food production is not in equal footings with population pressure (Central Statistical Agency, 2015); because Ethiopia is one of the sub-Saharan African countries where severe soil nutrient depletion restrains agricultural crop production and economic growth. The annual per-hectare net loss of nutrients is estimated to be at least 40 kg N, 6.6 kg P and 33.2 kg K (Scoones and Toulmin, 1999). Continuous cropping, high proportions of cereals in the cropping system, and the application of suboptimal levels of mineral fertilizers aggravate the decline in soil fertility (Tanner *et al*., 1991; Hailu *et al*., 1991; Workneh and Mwangi, 1992). Strengthening food production capability of the country by wisely exploiting its existing human and natural resources is critical option to avert the existing situation. Thus, identification of the proper fertilizer mix is one of the beneficial means at the macroeconomic level that improving the efficiency of fertilizer procurement and resource allocation. It is generally understood that crop response to fertilizer inevitably declines, if nutrient applications are continually unbalanced.

Crop production can be profitable if and only if balanced and adequate levels of phosphorus (P) and other nutrients are used. So, at this volatile grain and fertilizer prices condition, sound soil test calibration is essential for successful fertilizer program and crop production. It is essential that the results of soil tests could be calibrated or correlated against crop responses from applications of plant nutrients in question as it is the ultimate measure of a fertilization program. An accurate soil test interpretation requires knowledge of the relationship between the amount of a nutrient extracted by a given soil test and the amount of plant nutrients that should be added to achieve optimum yield for each crop (Sonon and Zhang, 2008). Therefore, Calibrations are specific for each crop type and they may also differ by soil type, climate, and the crop variety. That means, fertilizer recommendations on soil test basis for economic crop production should be both location and situation specific and can be modified with changes in soil test value as well as input output ratios. Based on this concept, soil test calibration study was made on teff at Lume district since 2010 having the following objectives.

Objectives

- To determine and evaluate P fertilizer requirement for teff crops based on soil test crop response in Lume district
- To determine optimum level of nitrogen fertilizer rate for teff in Lume district
- To give quantitative guidelines and recommendations of P fertilizer for teff crop in Lume district

MATERIALS AND METHODS

Descriptions of study area

The study was conducted at Lume district, East Shewa Zone of Oromia regional state, which capital town located at 73 kilometers far from Finfine (Addis Ababa) to the East. Geographically Lume district located between 8^0 24'300" to 8^0 49'30" North and 39^0 01'00" to 39^0 17'00" East with total area coverage 67514.73 hectares (Figure 1). The Elevation ranges from 1590 to 2512 meters above sea level, whereas the average elevation is 1909 meters above sea level.

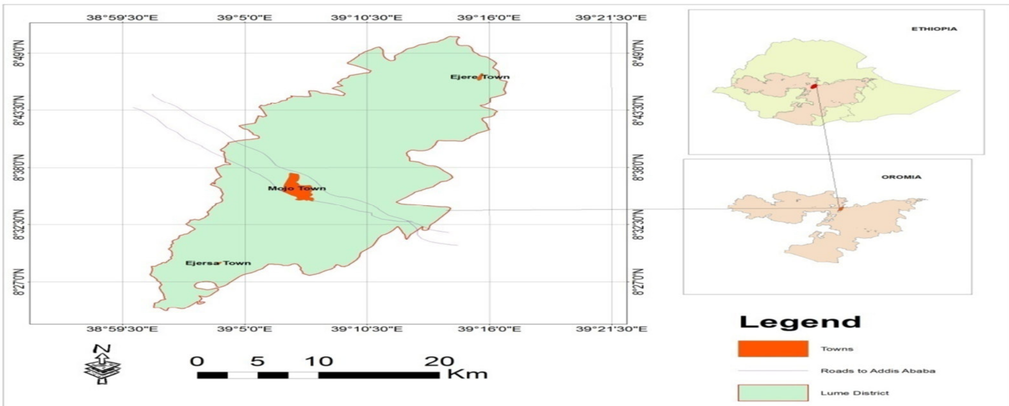

Figure 1: Location map of Lume district

Climate

Lume area is generally characterized by semi-arid and sub-humid climate based on the moisture index classification of climate (Lemma Gonfa, 1996). The long term average seasonal (June -September) rainfall which influence the rain fed agricultural practices of the year, ranges from 571.86 to 920.44 mm. The minimum monthly average rainfall of 2.70 mm was recorded at Modjo station in the month of December and maximum monthly average rainfall of 276.07 mm at the same station in the month of July. The mean monthly rainfalls of five stations within and nearest to the study area were calculated from the 20 years of data from 1999 to 2009, which was collected from National Meteorological agency (Figure 2). On other hand, the maximum mean monthly temperature of 32.13 ^oC was recorded at Koka dam station in month of April whereas the lowest minimum mean monthly temperature of 6.86 ^oC was recorded at Chefe-Donsa station in month of December. Hence, crops growth is influenced by total daily mean heat accumulated, which is related to the daily mean temperature (White *et al.,* 2001). Figure 3 shows the monthly minimum and maximum temperature of four stations within and nearest to Lume district.

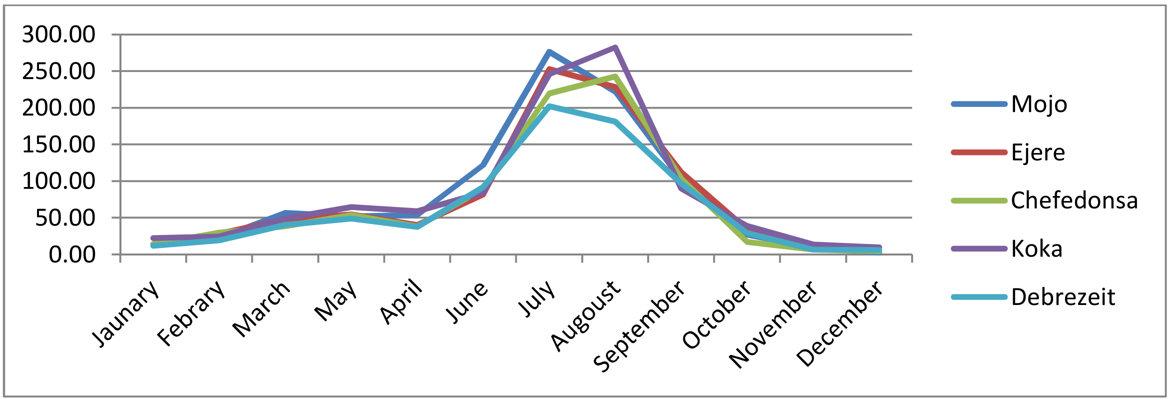

Figure 3. Monthly rain fall of five stations with in and nearest the district

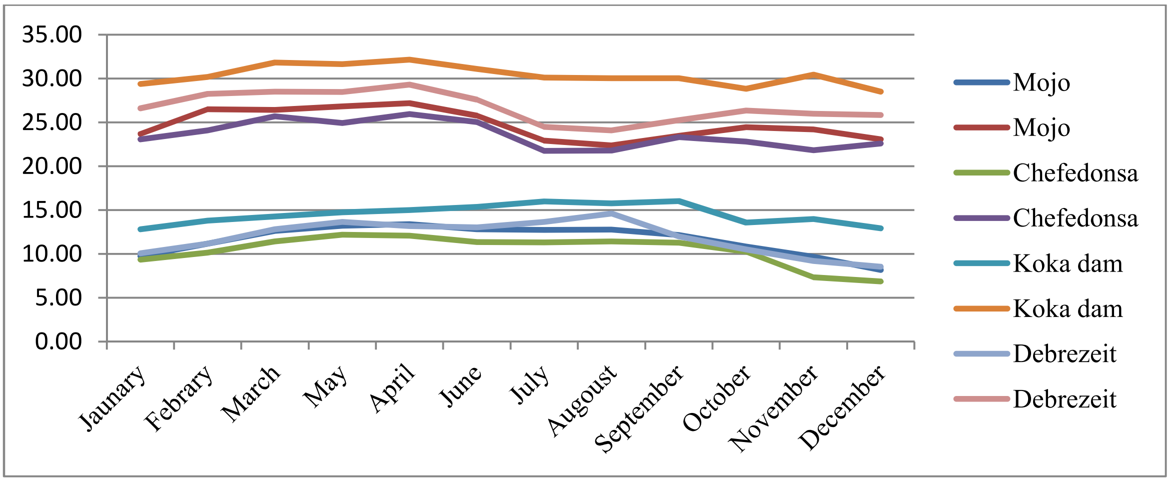

Figure 3. Monthly minimum and maximum temperature

Soil

Soil is defined (Davidson, 1980) as a natural body consisting of layers or horizons of mineral and / or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biological characteristics. According to FAO soil classification the soil of Lume district grouped into seven soil type, which is mainly dominated by Eutric Vertisol (44.84%), mollic andosols (21.69) and Luvic Phaeozems (14.76), (Appendix Table1).

Land Use Land Cover

The farming system of the study area is sedentary mixed agriculture and crop rotation is also one of the systems of soil fertility management in advancement. Chemical fertilizer application is another system to increase crop production per unit area. The major crop types in the area are teff, chickpea and wheat. These crops are scaled up by development agents and farmers on the basis of their economic benefits. This indicates that no crop type mainly dominate the area for a long year as the past historical farming systems with less inputs and market assessment and prediction. Generally, major land use of the project area is grouped into four (Appendix Table 2) that includes Agricultural land (93.13%), Plantation forest (2.76%), settlements (2.34%) and flower farms (1.77%).

Methodology

The study was conducted on farmers' fields across the district. First composite soil samples was made in zigzag method from **20 f**armers land and analyzed for soil texture, soil pH, OC, total N, available P, available K, CEC in order to identify the level of the required parameters in the soil to select farm land for actual experiment. Based on the level of P content a total of 10 farm lands were selected. The experiment was laid out in randomized complete block design with two replications. The treatment considered were four levels of P_2O_5 (0, 23, 46, and 96)s and four levels of N (0, 46, 92 and 138) in a factorial combination (Table. 1). Replications were folded to minimize soil heterogeneity within each replication.

Table 1. Description of treatments

Treatment # (T1-T6) *($N:P_2O_5$ kg ha^{-1})*	Treatment # (T7-T12) *($N:P_2O_5$ kg ha^{-1})*	Treatment # (T13-T18) *($N:P_2O_5$ kg ha^{-1})*
T1 *(0:0)*	T7 *(46:46)*	T13 *(138:0)*
T2 *(0:23)*	T8 *(46:92)*	T14 *(138:23)*
T3 *(0:46)*	T9 *(92:0)*	T15 *(138:46)*
T4 *(0:92)*	T10 *(92:23)*	T16 *(138:92)*
T5 *(46:0)*	T11 *(92:46)*	
T6 *(46:23)*	T12 *(92:92)*	

Gross plot size: 5m x 8m Harvested area: 3m x 3m

Land preparation was done using the local ox plow. Then, amount of seed and fertilizer per plot were weighed, teff seeds and fertilizers (total DAP and half urea) were sown by scatter method whereas half of the urea was sown 21 days after plantation. After 21 days of plantation before half urea application, composite soil samples were taken at 0-15 cm depth using auger for each treatment and replications separately, and the samples were subjected to laboratory analysis using Olsen method. With continuous field management, all field agronomic data and post harvest data were collected including, date of emergency, date of flowering, number of tiller, number of cob, maturity date, height, yield and biomass. Based on soil available P laboratory analysis result of pre-planting and post planting soil composite samples (available P values in samples collected from unfertilized and fertilized plots) data, P requirement factor was calculated that enables one to determine the quantity of P required per hectare to raise the soil test by 1 mg kg^{-1} (1 part per million), and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level.

Hence: Pr = kg P applied per change in soil P

For the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. This was achieved by overlay of a clear plastic sheet having a pair of perpendicular lines drawn on it to produce four quadrants, roughly of the same relative size. The overlay was then positioned on the graph in such a way that the maximum number of points fell in the positive quadrants while the lowest number fell in the negative quadrants. The vertical line defines the responsive and non-responsive ranges while the optimum is indicated by the point where the vertical line crosses the x-axis. Data from 10 sites for each crop and all treatments with their replications were used for such analysis**.**

On the other hand, economic analysis was performed to investigate the economic feasibility of the treatments and to determine the optimum rate of nitrogen. Partial budget, dominance, marginal and sensitivity analyses were used. The average yield was adjusted downwards to reflect the difference between the experimental plot yield and the yield farmers will expect from the same treatment. The average yield also adjusted reducing by 10% to minimize over estimation of grain while converting yield of small plot to hectare base. The average open market price (Birr kg^{-1}) of teff, prices of urea (N) and DAP (P) fertilizers were used for analysis. For a treatment to be considered a worthwhile option to farmers, the minimum acceptable rate of return (MARR) should be 100% (CIMMT, 1988), which is suggested to be realistic. This enables to make farmer recommendations from marginal analysis.

Finally, using Phosphorus requirement factor, Phosphorus critical level and initial P values (soil P value from composite soil sample before fertilization) rate of P fertilizer to be applied was calculated as follows:

Rate of P fertilizer to be applied = (Critical P conc.- initial P values) × P requirement factor.

Data collection

During field experiment the agronomic data collected were planting date, germination date, plant height, number of tillers, maturity date, bio-mass and grain yield.

Data Management and Analysis

All agronomic and soil data which were collected across locations was properly managed using the EXCEL computer software. The collected data was subjected to the analysis of variance using the SAS computer package version 9.0 (SAS Institute, 2002) statistical software.

RESULTS AND DISCUSSION

A field experiment was designed and studied to identify plant response to the applied P at specified site. Having this in mind, trial on teff was done at Lume district from 2010-2012 on 10 farms land to determine soil P and N optimum to be applied. This field experiments was done with the basic assumption that fertilizer recommendations typically depend on crop response experiments in which spatial variability has been minimized for every independent variable affecting crop yield except for the nutrient in question, although many non-fertility variables viz. soil texture, soil bulk density, available water content and other fertility variables significantly impact crop yield (Kastens et al., 2003).

Experimental data analysis of teff crop result indicated that, most of the treatments significantly produce mean grain yield as compared to the control. That means, except treatment 2, 3, 4, 5 and 13, all the rest produce significant mean grain yield as compared to the control (Table 2). Accordingly, the mean grain yield ranged from 772.74 kg/ha (control) to 1392.20 kg/ha (92 P_2O_5 level/treatment 16/). This result signifies that the existence of positive interaction of P and N fertilizers for the production of teff crop, and the responsiveness to the application of high level fertilizer phosphorus. Similarly, previous research output reported by Desta (1978), Mesfin (1980) and Asnake and Tekalign (1991), also supports this experimental result. According to Mesfin Kebede, and Tekalign Tadesse (2012), experiment made in 2005 at Chefe Donsa, Ude and Akaki on durum wheat, highest yield was observed at soil tests P raised to 6.91, 7.39 and 7.40 ppm, respectively. But low mean grain yield of teff for the experiment was because late starting of rain from normal rainy season that highly enhances weed infestation.

On the other hand, the experimental result also indicated that, consistently increment and significantly difference of all required teff agronomic parameter (plant height, straw yield and grain yield) as compared to zero as well as between levels, with the increment level of fertilizer N applications. These significant differences on agronomic parameters with required N fertilizer levels signify very low soil capacity to supply crop with N nutrient. Conversely, except between zero and the rest fertilizer P level, the increment of the level of fertilizer P did not resulted in significant difference between all levels for all agronomic parameter (Table 3and 4). These were might be because of initial (unfertilized soil) P level of the soil. But the Correlation coefficient between agronomic parameter (Plant height, straw yield and Grain yield) on teff crops were statistically significant at 0.05 probability level (Table 5).

Table 2. Response of teff grain yield to NP fertilizers application on Eutric Vertisol soil

Fertilizer		P			
	Trt	0	23	46	92
N	0	772.74[c]	827.79[c]	782.95[c]	798.89[c]
	46	909.54[bc]	1155.97 [ba]	1193.18[a]	1393.62[a]
	92	914.99[bc]	1199.43[a]	1244.85[a]	1305.1 [a]
	138	814.45[c]	1154.86[ba]	1245.34[a]	1392.20[a]
	LSD (0.05)	269.99			
	C.V %	23			

Table 3: Effect of P (kg/ha) applied on plant height, straw yield and grain yield on Teff crop at Lume District.

	Agronomic parameter		
P (kg/ha)applied	pt Ht(cm)	Syld(kg/ha)	Gyld(kg/ha)
0	86.84b	1071.91b	846.91c
23	90.41ba	1214.42ba	1084.52b
46	89.70ba	1330.05a	1116.58ba
92	91.49a	1367.68a	1227.47a
LSD < 0.05	3.59	158.45	134.81

*Pt Ht = (plant height cm); Syld = Straw yield(kg/ha); Gyld = Grain yield(kg/ha); LSD = Least Significance Difference

Table 4: Effect of N (kg/ha) applied on plant height, straw yield and grain yield on Teff crop at Lume District.

	Agronomic parameter		
N kg/ha)applied	pt ht(cm)	Syld(kg/ha)	Gyld(kg/ha)
0	82.42a	881.35a	786.47a
46	88.74b	1216.48b	1164.71b
92	92.94c	1426.98c	1166.10b
138	94.12c	1449.25c	1151.74b
LSD < 0.05	3.6	158.8	135.1

*Pt Ht = (plant height cm); Syld = Straw yield(kg/ha); Gyld = Grain yield(kg/ha); LSD = Least Significance Difference

Table 5: Correlation coefficient between Plant height, straw yield and Grain yield on Teff crop at Lume District.

	Correlation coefficient		
	pt ht(cm)	Syld(kg/ha)	Gyld(kg/ha)
plant height ht(cm)	1.00	0.48(<.0001)	0.521(<.0001)
Straw yield (kg/ha)	0.48(< .0001)	1.00	0.513(<.0001)
Grain yield (kg/ha)	0.521(<.0001)	0.513(<.0001)	1.00

*Pt Ht = (plant height cm); Syld = Straw yield(kg/ha); Gyld = Grain yield(kg/ha)

Figure 4. Field picture of experimental teff

Determination of Optimum Nitrogen Fertilizer Application for Teff

Optimum yield can be gained in the presence of all available essential nutrients at balanced and optimum level where phosphorus and nitrogen are the most deficient essential nutrient in the country. Therefore, determination of optimum nitrogen fertilization level during P fertilizer calibration is the most important procedure. Hence, determination of optimum nitrogen fertilization level was done by partial economic analysis procedure, which is **46 kg N/ha** for teff on Eutric vertisols soil for Lume area.

Determination of P Critical for Teff

For the determination of critical values of P, the Cate-Nelson diagram method (Nelson and Anderson, 1977) was used, where soil P values were put on the X-axis and relative yield values on the Y-axis, and scatter points were divided into two populations. Then, by moving the two perpendicular lines vertically and horizontally, until the number of points showing through the overlay in the two positive quadrants is at a maximum (or conversely, the number of points in the negative quadrants is at a minimum). Finally, the point where the vertical line crosses the X-axis was defined (taken) as 'critical soil test levels. Hence, P critical value for teff at Lume area on vertisols soil were **13ppm** (Figure 4)

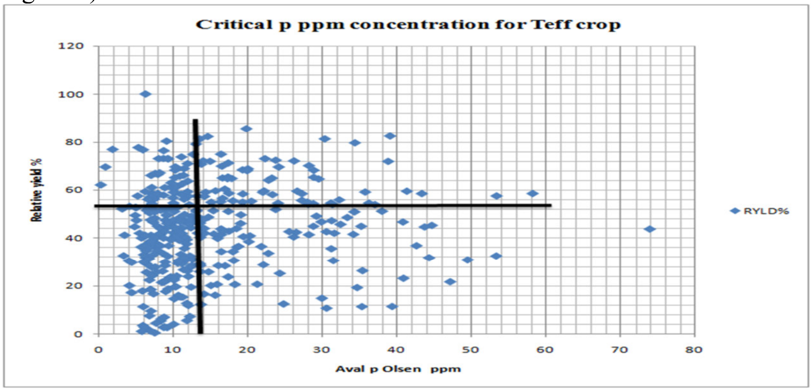

Figure 4. Relative yield Vs P Olsen plot chart for P critical determination

Determination of Phosphorus Correction Factor (Pf)

Calculated phosphorus requirement factor (Pr), which is the amount of P in kg needed to raise the soil test P by 1ppm for teff crops production at Lume area was **3.65**. These Phosphorus requirement factor enables to determine the quantity of P required per hectare to raise the soil test by 1 ppm, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Table 4).

Table 4. Determination of P requirement factor (Pf) for teff, Lume district

Fertilizer treatment kg P ha^{-1}	Olsen - P (ppm)		P increase Over control	*P requirements factor = kg P P^{-1}(ppm)
	Range	Average		
0	3.25-49.46	10	0	0
10	0.19-35.16	13.1	2.9	3.45
20	1.78-73.92	15.43	5.43	3.68
40	4.82-58.12	20.45	10.45	3.83
Mean for Olsen				**3.65**

CONCLUSION AND RECOMMENDATIONS

- Site specific soil test based crop response Phosphorus calibration study has been conducted on teff for two years (2011-20012 growing season) at Lume district.
- Accordingly, Optimum nitrogen rate (46 kg N/ha), critical P (Pc) concentrations (13 ppm) and P (Pf) requirement factors (3.65) for teff have been determined, at Lume teff growing area on eutric vertisols soil.
- Farther verification of the result on farm land could be a pre request before disseminating the technology to the user.

Acknowledgements

First of all, we thank our God who enables us, in all circumstance, to perform our research activity properly. Secondly, the authors would like to thank Oromia Agricultural Research Institute and Zeway Soil Research Center for funding the research and providing all the necessary facilities required for the research, respectively. At last but not at least, our special thank also forwarded to all staff members, especially to laboratory analysis team for their support and unreserved effort to provide reliable samples analysis data on time.

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