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Soil Test-Based Phosphorus Calibration Study for Chickpea (*Cicer arietinum*) on Vertisol of Dendi District Under Balanced Soil Fertilization in Central Ethiopia

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Abstract: Optimal essential nutrient management under balanced soil fertilization becomes crucial as natural resources utilization increasing with limited supply of resources specially on those of nonrenewable ones by taking this into consideration soil test based phosphorus calibration study under balanced soil fertilizer application were studied on vertisols of Dendi district in Ethiopian central highland on chickpea (*Cicer arietinum*) crop at 2019 cropping season in Ginchi substation permanent plot which is managed for four successive years to implement those phosphorus calibration trials. Fertilizer treatments were applied at planting and soil samples were collected three weeks after planting to analyze Olsen extractable phosphorus which is correlated to relative chickpea grain yield and determine the critical soil phosphorus level (by using Cate- Nelson graph method) and phosphorus requirement factors of chickpea on vertisols accordingly it was determined as 11.9 mg kg^{-1} of soil and 8.97 mg kg^{-1}, respectively. From the aggregate mean data analysis result the highest chickpea grain yield, biomass yield and other related yield components was obtained from 30 kg P ha^{-1} application rate with 20 kg starter Nitrogen ha^{-1}, 7 kg Sulfur ha^{-1} and 0.51 Kg Boron ha^{-1}. The least result in all parameters was obtained from control treatment which has 0 P level.

Key words: Vertisol · Phosphorus · *Cicer arietinum* · Ginchi · Critical P. · Phosphorus Requirement Factor

INTRODUCTION

Ethiopian Vertisol covers 12.5 million hectare which is 10.2% of countries soil type coverage ranked 4th next to Lithosols, Cambisols and Nitisols covers 16.2, 15.3 and 11.8% of the counties soil type coverage respectively [1]. Chickpea is from the most dominant legume crops which is grown on the highlands of Ethiopia with wide soil type adaptation, Ethiopia is the largest chickpea producer in Africa, with a share of about 39% of total chickpea produced there in 2011 [2]. Chickpea is mainly grown in the central, north eastern highland and southern region of Ethiopia with altitude ranging 1400-2300 masl, Yadessa Anbessa and Geletu Bejiga [3]. Availability of nutrients to crops is a function of the soil, crop, environment and management; their interactions affects fertilizer use efficiency and the crop growth condition [4]. Most Ethiopian soils are majorly poor in their N and P contents indicating that areas growing legumes are also low in N and P [5] However, the degree of deficiencies of those major essential nutrients varies depending on soil type, crop species and environmental conditions. This implies that there is a need to test and establish optimum fertilizer rates for optimal crop production.

Insufficient application of Phosphorus fertilizer below crop requirement was the major constraint which limits its productivity [6, 7] on the other hands excessive or inappropriate applications rate of P fertilizers have a direct negative impact on surface waters that influence the functioning of ecosystems [8] beyond economical losses. Thus, to realize a sustainable P use in agriculture, it is important to optimize soil P management to achieve optimal crop yield, minimize potential adverse effects on

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environment and limit the accumulation of soil P to certain target levels [9]. Therefore, for a better P management, determining the critical value of soil Olsen-P to optimize P fertilization in Chickpea crops is crucial. The critical value of soil Olsen-P is the value of soil Olsen-P above which the probability of crop response to P fertilization is negligible [10-12]. Critical values of soil Olsen P differ among crops because of different P requirements and P uptake efficiencies [13]. The critical values of soil Olsen-P range from 3.9 to 15 mg kg^{-1} for maize [14] and from 4.9 to 20 mg kg^{-1} for wheat Johnston *et al.* [15], Bollons and Barraclough [16] and Colomb *et al.* [17]. Thus, this experiment was conducted on vertisols of Dendi wereda located in Central Ethiopia to determine the response of chickpea to different P Fertilizers rates with respect to determining the critical P and P requirement factor which helps to determine the soil test-based P fertilizer application under balanced essential nutrient supply in need for improving the production of chickpea crop.

MATERIALS AND METHODS

Experimental Location: The field experiment was conducted to determine Phosphorus response of chickpea (*Cicer arietinum*) on permanent fields in West Shewa zone, at Dendi wereda, Ginchi research station Located at DMS Lat 9°01'20.28" N and Longitude 38° 10'56.67" E; 2208 masl. altitude in 2019 cropping season (Figure 1). The area is characterized by a unimodal rainfall pattern and receives an average annual rainfall of 1080 mm, about 85% of which is received from June to September. The soil of the area is characterized as vertisol, which is black in color and clay in texture and its pH ranges 5.8 to 7.2. The dominant crops produced in the district are mostly cereals, pulses, oil seeds and vegetable crops.

Soil samples were taken three weeks after planting by using auger sampler at plough depth (0-20 cm) five spot sample was collected from each experimental unite and composite for each experimental plot to investigating soil properties of each treatment. The collected soil samples were bagged, labeled and transported to the laboratory for preparation and analysis of soil properties. Sufficient amount of composite soil samples was air dried and ground to pass through a 2 mm sieve in preparation for the analyses of the selected physicochemical properties following standard laboratory procedures [18]. The collected samples were analyzed for the determinations of pH (by using H_2O 1:1.25 ratio Method), organic carbon OC (Walkley and Black [19] method), total N Kjeldahl method [20]; available P (Olsen extraction method) and cation exchange capacity CEC (ammonium acetate) at Holeta Agricultural Research Center soil and plant analysis laboratory. The available soil P ranges prior to planting considered for classification were <13 ppm for low, 13-30 ppm for medium and >30 ppm for high available P by Olsen method [21] for heavy clay vertisol according to Clements and McGowen [22]. Based on this categorization, an experimental field was created in four gradient groups with low, medium and high phosphorus fields.

Experimental Design and Procedure: The experiment was arranged in RCBD with five levels of phosphorus (0, 10, 20, 30 and 40 kg P ha^{-1}) and three replications. On the first year the field was grown maize for exhaustive trial without fertilizers and at second year a field was divided into 4 strips, which was 4 doses of Phosphorus ($P_0+(N_1S_1B_1)$, $P_{1/2}+(N_1S_1B_1)$, $P_1+(N_1S_1B_1)$ and $P_2+(N_1S_1B_1)$ was applied. Similarly, on the third year the plots were again follow the same procedure each of the plots divided into 4 strips. Finally, on the 4th year the experimental field was 16 (4x4) and five P levels with three times replication (15) was implemented on each of the experimental field. The total experimental unit becomes 240 plots (16 Field * 5 Trt. * 3 rep. = 240). The experiment was conducted in the same field for four years in order to study the residual effects. The gross plot size was 2m x 2m ($4m^2$) with 40cm*10cm row and plant spacing respectively. The spacing between blocks was 1m and between plots was 0.5 m. Urea and TSP (Triple super-phosphate) was used as Sources of starter N and P other essential nutrient (S and B) was applied based on site-specific fertilizer recommendation from EthioSIS [23] 7 kg Sulfur ha^{-1}, 0.51 kg ha^{-1} Boron and 20 kg ha^{-1}Starter Nitrogen was used at planting with the same rate uniformly for all treatments. by using calcium sulfate, borax and urea sources respectively in uniform application for entire experimental plots.

Land preparation was done at the end of May in accordance with a standard practice locally used. The experimental plot was cultivated by an oxen-drawn implement to the depth of 0-30 cm. The land was levelled and ridges were made manually. Chickpea Arerti improved variety was planted by using 140 kg ha^{-1} seed rate. Cultivation, weeding, chemical spray and harvesting were done at the appropriate time according to the research recommendations. Application of phosphorus fertilizer was done by banding the granules of TSP at the depth of 5 cm below at planting also starter Nitrogen was applied at planting ones.

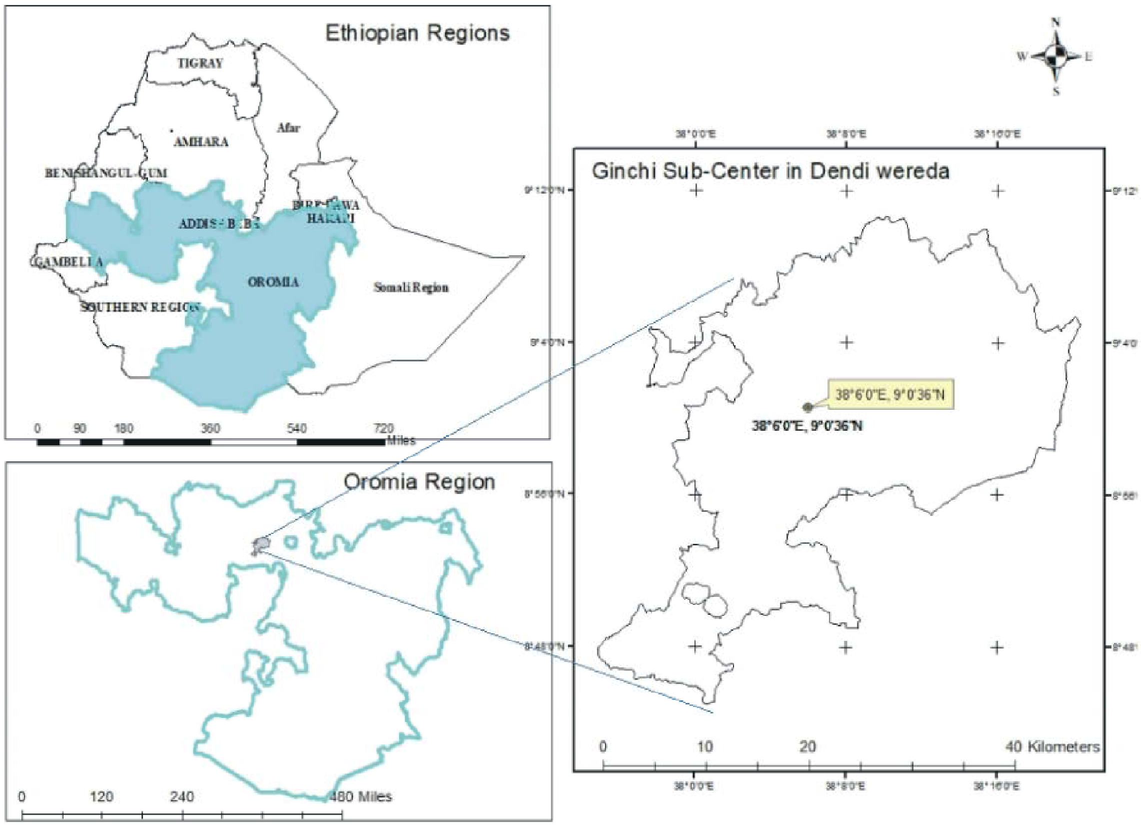

Fig. 1: Study site map of Ginchi sub center where soil test-based P calibration trial was conducted in 2019

Data Collection: Growth parameter data were taken from five representative plants per plot and the whole plot was harvested for yield and biomass data. Plant height was measured from the ground level to the tip of the plant at physical maturity in cm. number of primary branches and number of pods per plant data was collected at harvesting. After threshing, the seeds were cleaned, weighed and the moisture content was measured. Total biomass (dry matter basis) and grain yields (adjusted to moisture content of 12.5%) recorded on plot basis were converted to kg ha^{-1} for statistical analysis.

Determination of Critical P Concentration (Pc): To correlate relative yield vs soil P values and determine critical P concentration, the available P was extracted from the soil samples which taken three weeks after planting from each plot of all experimental fields using Olsen method. The Cate-Nelson graphical method [24] was determine the critical P value using relative yields and soil test P values obtained from 16 P fertilizer trials field conducted at different P levels. To assess the relationship between grain yield response to nutrient rates and soil test P values, relative grain yields in percent were calculated as follows:

$$Relative\ yield\ (\%) = \frac{Yield}{Maximum\ yield} X100$$

The scatter diagram of relative yield (y-axis) versus soil test values (x-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular lines was drawn to divide the data into four quadrants. The vertical line defines the responsive and non-responsive ranges. The observations in the upper left quadrants overestimate the P fertilizer P requirement while the observations in the lower right quadrant underestimate the fertilizer requirement. The intersecting lines were moved about horizontally and vertically on the graph, always with the two lines parallel to the two axes on the graph, until the number of points in the two positive quadrants was at a maximum (or conversely, the number of points in the two negative quadrants was at a minimum). The point where the vertical line crosses the X-axis was defined as optimum critical soil test level [24].

Determination of P Requirement Factor (P_f): Is the amount of P in kg needed to raise the soil P by 1 mg kg^{-1}. It enables to determine the quantity of P required per hectare to raise the soil test by 1 mg kg^{-1} and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level [25]. Using to calculated available P values in samples collected from unfertilized and fertilized plots on the same treatments result of soil sample was taken after three weeks become varies, the result put by range from minimum – maximum and used to calculate value of P increase over the control. Phosphorous requirement factor was expressed as:

$$Pf = \frac{P\ applied\ (kg)}{\Delta\ soil\ P}$$

Therefore, the rate of P fertilizer to be applied (Pa) was expressed in terms of critical P concentration (P_c), initial soil P value (P_i) and P requirement factor (P_f).

$$Pa = (Pc - Pi)\ xPf$$

Statistical Analysis: All plant growth parameters, above ground dry biomass, grain yield data and soil available P after three weeks of planting or treatment application data were subjected to analysis of variance by using the procedure of the SAS statistical package version 9.0 software at $P<0.05$ level, means for the main effects were compared using the least significant difference (LSD) method.

RESULTS AND DISCUSSION

Ginchi substation where Soil test Phosphorus calibration study is done have soil particle size distribution of 67.1% clay, 22.1% silt and 10.8% sand which is classified as heavy clay soil texture with dark black vertisol [26]. It was sub divided into four sub block which have pH ranges from 6.42 to 6.67; available P from 4.31 to 7.95 average soil test results. Other properties also vary from sub experimental field as summarized in (Table 1).

Statistical analysis of variance showed that all growth parameters and yield (BMS and GYD) were significantly ($P<0.05$) affected by soil taste base phosphorus application on vertisol of Ginchi area for chickpea crop. accordingly, the highest mean plant height 48.92 cm was recorded from higher P application rate at 40 kg P ha^{-1} (92 kg P_2O_5 ha^{-1}) although it was statistically the same for other treatments except control. Average number of branches per plant was highest 4.58 at 10 kg p ha^{-1} which is also statistically the same for all treatments except control. Number of pods per plant result was highest at 30 kg P ha^{-1} (69 kg P_2O_5 ha^{-1}).

Other Study on P rate for chickpea pea in northern Ethiopia Seid [27] also confirmed that the maximum number of pods per plant were recorded in fertilizer at optimum application (60 kg P_2O_5 ha^{-1}). which increase in the number of pods per plant with the application Phosphorus was resulted from more pronounced growth of the chickpea crop which in turn had increased number of pods per plant. Phosphorus is a very important nutrient needed for effective nitrogen fixation because symbiotic N fixation is very high energy demanding process in the form of ATP which has P as its major component in general, soils with low extractable P will have poor nodulation and poor plant vigor [28, 29].

Biomass and grain yields were showing the same trend on mean separation result. statistically highest grain yield was recorded from 30 kg P ha^{-1} (69 kg P_2O_5 ha^{-1}) similarly highest biomass yields 8232.7 kg ha^{-1} was obtained from the same treatment followed by 40 kg P ha^{-1} with competent biomass and grain yields in terms of statistical analysis both treatments have the same variation whereas application rate 40 kg P ha^{-1} (92 kg P_2O_5 ha^{-1}) were not preferable since the yields were started to decline and application rate increases without yield increments. In all crop growth parameter and yield data the least result was recorded from control (0 kg P ha^{-1}) treatment. Using 30 kg P ha^{-1} application rate have got grain and biomass yield advantage of 56.5 % and 22.15 % over the control treatment respectively. And it also had grain yield advantage of 9 %, 7 % and 0.6 % over the other phosphorus rates 10, 20 and 40 kg P ha^{-1} respectively.

Similar study in the same location on tef crop reviled that application rate of P at 30 kg ha^{-1} can gave maximum yield advantage over other application rate [30]. According to Islam [31], the yield of chickpea was increased by 65 % and 88 % due to the application of P fertilizers in Pakistan and Jordan respectively. However, the optimum P - requirement for adequate production of chickpea varies from soil to soils. Study in Southern Ethiopia also confirmed that different rates of P fertilizer were performs differently based on the level of available soil P [32] accordingly 20 and 30 kg P ha^{-1} treatments were at par statistically with each other with respect to yield whereas, The effect of P fertilizer treatments in individual locations, the highest and optimum yield was obtained from 20 kg P ha^{-1} whereas in Taba the optimum yield was obtained from 10 kg P ha^{-1} which have 8.1 and 18.2 ppm on Andosol and vertisols mean soil available P respectively. From this observation we can deduce that we should be very careful and interpreting data analyzed over location based on soil type and soil extractable phosphorus.

Table 1: Ginchi sub center experimental site major soil properties before treatment application

Trial field	pH (H_2O) 1:1.25 ratio	Phosphorus (ppm) Olsen	Nitrogen (%)	CEC (meq /100g of soil)	OC (%)	OM (%)
1	6.42	4.31	0.21	18.51	2.3	3.96
2	6.51	5.24	0.24	20.32	2.5	4.30
3	6.49	5.63	0.27	21.12	2.7	4.64
4	6.67	7.95	0.28	22.19	2.8	4.82
Mean	6.52	5.78	0.25	20.54	2.58	4.43

where CEC cation exchange capacity; OC organic carbon in percent and OM is soil organic mater

Table 2: Growth parameter and yields of chickpea as affected by soil test-based phosphorus application at Ginchi

Treatments	Ph (cm)	Branch per plant	No. of pod per plant	GYD kg/ha	BYM kg/ha
0 kg P ha^{-1}	46.40 B	4.13 B	46.19 B	1491.5 D	6739.7 D
10 kg P ha^{-1}	47.60 AB	4.58 A	49.70 AB	2135.1 C	7793.9 C
20 kg P ha^{-1}	47.63 AB	4.43 AB	50.63 AB	2165.6 BC	7806.1 BC
30 kg P ha^{-1}	48.18 AB	4.55 A	51.87 A	2334.2 A	8232.7 A
40 kg P ha^{-1}	48.92 A	4.56 A	51.28 A	2319.8AB	8196.1 AB
Means	47.7	4.4	49.9	2097.6	7753.7
Cv (%)	9.7	21.8	24.2	19.8	12.8
Lsd (5%)	1.87	0.39	4.87	166.7	400.5

where: ph is plant height in cm GYD grain yield in kg/ha, BYM is above ground dry biomass in kg per hectare. Means with the same letter in the same column don't have statistically significant difference.

Table 3: Soil test Olsen available P range; P increase over control and phosphorus requirements factors for different P application rates on vertisol of Ginchi area

		Soil Available P (ppm) after 3 weeks of planting				
No.	Treatments	Min	Max	AVG	P Increase	P_f
1	0 kg P ha^{-1} + 20 N, 7 S, 0.5 B kg. ha^{-1}	4.3	11.9	7.69 C		
2	10 kg P ha^{-1} + 20 N, 7 S, 0.5 B kg. ha^{-1}	5.2	14.8	9.02 B	1.1	7.51
3	20 kg P ha^{-1} + 20 N, 7 S, 0.5 B kg. ha^{-1}	5.6	16.8	9.81 B	1.8	9.45
4	30 kg P ha^{-1} + 20 N, 7 S, 0.5 B kg. ha^{-1}	6.3	21.8	11.19 A	2.8	8.57
5	40 kg P ha^{-1} + 20 N, 7 S, 0.5 B kg. ha^{-1}	6.4	19.6	11.56 A	3.5	10.34
Means		5.6	17.0	9.7	2.70	8.97
Cv (%)				22.9		
Lsd (5%)				0.91		

where: P increase is over the control for each p rate; P_f is phosphorus requirement; Means with the same letter in the same column don't have statistically significant difference

Critical P Concentration (Pc) and P Requirement Factor (Pf): Soil test based different rate of phosphorus application at vertisols in Ginchi area was significantly affect available soil phosphorus status three weeks after treatment application or chickpea planting. accordingly, highest available soil P (10.8mg kg^{-1}) was obtained from soil test result of 40 kg P ha^{-1} application rate.

Mean P requirement factor of chickpea on vertisol of Ginchi for chickpea crop is determined as 8.97 ppm by using Olsen soil available P method of extraction as presented in (Table 3). The relationship between relative grain yield (y-axis) in (figure 2) response and soil test P (X- axis) measured with the Olsen method is shown in the 'Cate – Nelson' graph. The critical P (*Pc*) was determined from the scatter diagram drawn using relative grain yields of chickpea and the corresponding soil test P values for all P levels (0 – 40 kg ha^{-1}). The P*c* defined by the Cate- Nelson method in this study was about 8.91 mg P kg^{-1}, with mean relative grain yield response of about 80 %. The computed *Pf* value were ranges from 7.51 – 10.34 and the overall average phosphorus requirement (*Pf)* of all treatments for vertisol of Ginchi area was 8.97 ppm Thus the rate of P fertilizer required per ha can be calculated using the soil critical P concentration and the P requirement factor as indicated above in Pa formula. i.e. for the control treatment average soil p is 7.69 ppm so P to be apply computed as Pa = (11.9 – 7.69) * 8.97 there for the result will be 37.8 kg P $ha^{-1}$is required which is approximately 86.9 kg P_2O_5 ha^{-1} or 225.8 kg NPS.

Critical levels of Olsen soil P at surface depth 20cm of soil was about 11.9 ppm (Figure 2), at values of greater than or equal to 11.9 ppm, the crop can achieve about 80% of its maximal yield in the absence of P fertilizer application. This implies that P fertilizer application could

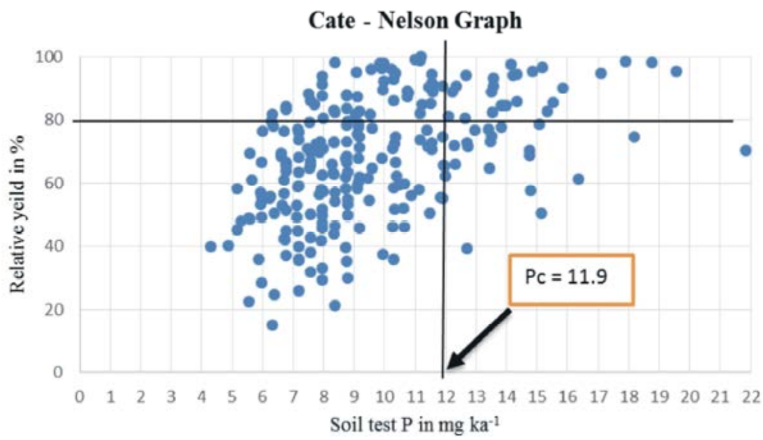

Fig. 2: Cate- Nelson graph of chickpea relative yield to soil P determine critical P level for Ginchi vertisol

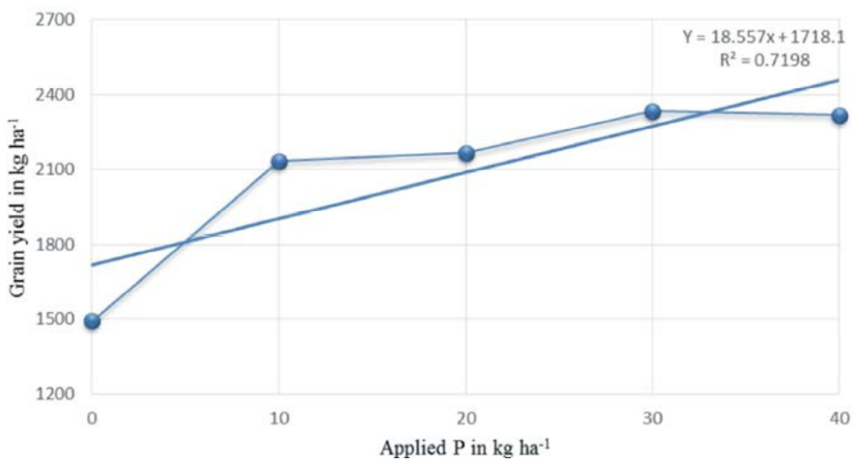

Fig. 3: Soil available P versus grain yield relation graph for soil test p calibration on vertisol of Ginchi

be recommended for maintaining the soil P at this level (maintenance application). Increasing P beyond this level, would incur additional P cost of fertilizer to produce extra yield which, likely being greater than the value of additional yield. Thus, in soils with Olsen available P below 11.9 ppm, yield of chickpea crop could show a significant response to applications of P fertilizers on vertisol of Ginchi area. Other study in related area of central Ethiopia also confirmed that application of P fertilizer above critical P level was not have significant yield increment [4, 33] and which is not economical compared to the cost of fertilizer application on Nitisols of Wolmera area soil for barley and wheat crops respectively. Likely soil test p calibration study results in north western Ethiopia shows that at values less than critical phosphorus levels of extractable P, Phosphorus fertilizers should be applied to increase maize yield [34]. These results can be used as a basis for soil-test P fertilizer recommendation for the production of chickpea crop in similar agro-ecology and soil type areas of central Ethiopian highlands.

As observed from the grain yeild versus applied P relation graph it up to the first 10 kg P application the yield encriment is increased exponentialy on the succiding rates the yield increament becomes relatively reduced after 30 kg P ha^{-1} fertilizer application the yield even stop to increase and starts to decline(Figure 3) so in the vertisol of Dendi wereda of central Ethiopian highland application of P fertilizer for chickpea with balanced fertilization based on soil test based P recomendation will inmpruve the crops productivity to the optimal crop potential. As the soil test level exceeds the critical phosphorus level shown in (Figure 2) application of P fertilizer rate should consided as maintenance application to substitute the specific nutrient which is mined in specific croping season. Mallarino [35] reported that a critical concentration of 13 mg P kg^{-1} for corn response within this category (13-20 mg P kg^{-1}) may be considered small and maintenance fertilization can be recommended based on expected nutrient removal with harvest.

CONCLUSION

Soil test based balanced fertilization have multiple advantage on effective utilization of fertilizers for various types of soil and to meet plant specific nutrient requirements with optimal nutrient supply for plant vigor and productivity. Crops varies on their nutrient requirements as previous study confirmed that phosphorus requirements of different crop species were varied depends on the soil type they are grown and other agro-ecologic factors. Chickpea crop are among the dominant crop grown on vertisol of Dendi wereda which have required balanced supply of P for optimal crop production in this study the P critical value is determined as 11.9 mg kg^{-1} of soil. And the P requirement factor which was needed to increase Olsen soil available P by 1ppm is 8.97 by using such factors one can determine the most appropriate fertilizer rate which is required to increase chickpea productivity to the optimal cost-effective way it also minimizes the excess losses of Phosphorus to the environment (surface water bodies). The mean statistical analysis result of overall fields P rate indicated that application of 69 kg P ha^{-1} gave the maximum grain yield and other related yield components as overall average result. to meet optimal crop p requirement, it is important to consider the Olsen available P in relation to specific soil crop critical level and determine the required amount with P factor which is provided in the result for Dendi wereda vertisol and similar agro-ecologies. They can also be used for future intensification in other areas for developing a system for soil test-based fertilizer recommendation although to develop a valid soil test phosphorous recommendation for more wider applicability using low, medium and high categories, several years of research is required to generate sufficient information for the most important crop- soil system.

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