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Critical Level of Extractable Phosphorus for Maize (*Zea mays* L.) at Metekel Zone, Northwestern Ethiopia

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ABSTRACT

Fertilizer recommendation based on choosing an effective soil nutrient extractants and calibrating soil tests against yield responses to applied nutrient has been little used in Ethiopia. An experiment was conducted during 2009, 2010 and 2011 cropping seasons in 35 different farmer fields from five Districts of Metekel zone. Six levels of phosphorus (0, 10, 20, 30, 40 and 50 kg ha^{-1}) arranged in Randomized Complete Block Design (RCBD) with three replicates were used to determine the critical level of phosphorus (P) for maize and to compare Bray II, Olsen and Mehlich III P extraction methods. Grain yield of maize responded positively and significantly to P fertilizer application of the study area. Compared with the control, grain yield increased 19.8 to 35.3% by applications of P fertilizers. Extractable P concentration extracted after three weeks of planting by using three extraction methods were significantly differed among P fertilizer rates. Using the Cate and Nelson graphical method, the critical levels of soil extractable P were 12, 8 and 10 mg P kg^{-1} soil for Bray II, Olsen and Mehilich III extraction methods, respectively. Results shows that at values less than these critical levels of extractable P, P fertilizers should be applied to increase maize yield. The Bray II P was more correlated (r = 0.38) with relative maize grain yield than and Olsen and Mehlich III extraction methods. In addition, the quantities of P extracted by the three extractants were in the following order: Bray II > Mehlich III > Olsen P extraction method. The result indicated that Bray II was found to be the most suitable as soil testing method for estimating extractable P in the study area.

***Keywords*:** Critical level; fertilizer; phosphorous; maize; soil test; extraction methods

1. INTRODUCTION

Next to nitrogen (N), phosphorus (P) deficiency is one of the most limiting factors for maize production in Ethiopia. Appropriate fertilizer recommendations must be used to sustain increased Maize yield. Accordingly, in northwestern Ethiopia, farmers usually use blanket recommendation of chemical fertilizers such as 100 kg Di-Ammonium Phosphate (DAP) ha^{-1} and 100 kg Urea ha^{-1} for P and N, respectively for maize grain production without considering the fertility status of a particular fields (Ermias *et al*., 2007). This blanket fertilizer recommendation for maize production in Ethiopia particularly in Metekel zone does not ensure efficient and economic use of fertilizers, as it does not take into account the fertility variations.

However, a controlled fertilization program through a sound soil test-crop response calibration and recommendation brings the application rates more in line with crop requirement, minimizes over- or under-application of fertilizer and could save hundreds of thousands of tons of fertilizer each year, minimizes the potential for water pollution due to over fertilization, especially N and P (Dahnke *et al*., 1992), and minimizes losses in yield and crop quality. Consequently, crop fertilizer recommendations based on soil test approach considers the fertility status of individual fields and believed to be more advantageous than blanket recommendation. Hence, soil test results correlated against crop responses from applications of plant nutrients in question is the ultimate measure of a fertilizer recommendation program in order to applying nutrients at the right rate and in the right place as a best management practice for achieving optimum nutrient efficiency (Roberts, 2008) and crop production.

Soil test calibration is the process of deciding the meaning of the extractable concentrations of the soil nutrient in terms of crop growth response or quality, which is completed using different methods. Cate and Nelson (1965) graphical method is one of the popular method which plots percent relative yield against soil test values which allows for the identification of a soil test critical level by dividing soil test levels into two classes that are a low class (response to an added fertilization) and high class (no response to an added fertilization). Critical level of a nutrient in soils refers to a level below which the crops will readily respond to fertilizer application and above which the response diminishes at a faster rate or vanishes. This level varies with crops, soil, and the extractants used. In Ethiopia, there have been some studies on the determination of critical limits of P using Cate-Nelson graphical method. For example, Getachew and Berhane (2015) reported that for malt barely under rain-fed conditions on Nitosoils of Ethiopian highlands the critical level of extractable P using Bray II method was about 12 mg kg^{-1} and the level beyond which an economic response by malt-barely could not be expected. Their findings were based on multiple locations on farm trials conducted in multiple seasons.

The various steps in establishing optimal rates for fertilizer include choosing extractant provides the indication a soil that best of the "extractable" nutrient in the soil, comparing the extractable nutrient with the response in yield of crops, Over the years, many different soil testing procedures and extracting solutions were evaluated in an effort to identify a method that provides the most reliable prediction of crop yield response to nutrient application. It was determined that some soil testing procedures are best suited for particular soil types and climatic regions, whereas other soil testing procedures are better suited for different soil types and climates (Haby *et al*., 1990).

Many soil P tests with different chemical extractants are used to extract P from soil as an indicator value of P extractable/ available for plants. Soil-test correlation can be used to select the appropriate method for soil P assessment, thereby taking account of plant extraction capacity from the specific soil. Accordingly, an appropriate soil test needs to be identified to assess P availability for maize as a tool for fertilizer recommendations in the study area. There are two soil P test methods (Bray II (Bray and Kurtz, 1945) and Olsen (Olsen *et al.*, 1954)) widely used by soil test laboratories in Ethiopia. In addition, Mehlich III (Mehlich, 1984) soil P test method also has been used by some soil test laboratories in the country. However, no information is available on the suitable soil P test method and critical level of P in soils of the study area for Maize. Hence, multiple-season and multiple-location on farm field experiments were conducted to determine the critical level of P for maize production and to compare Bray II, Olsen and Mehlich III P extraction methods.

2. MATERIALS AND METHODS

2. 1. Description of the Study Area

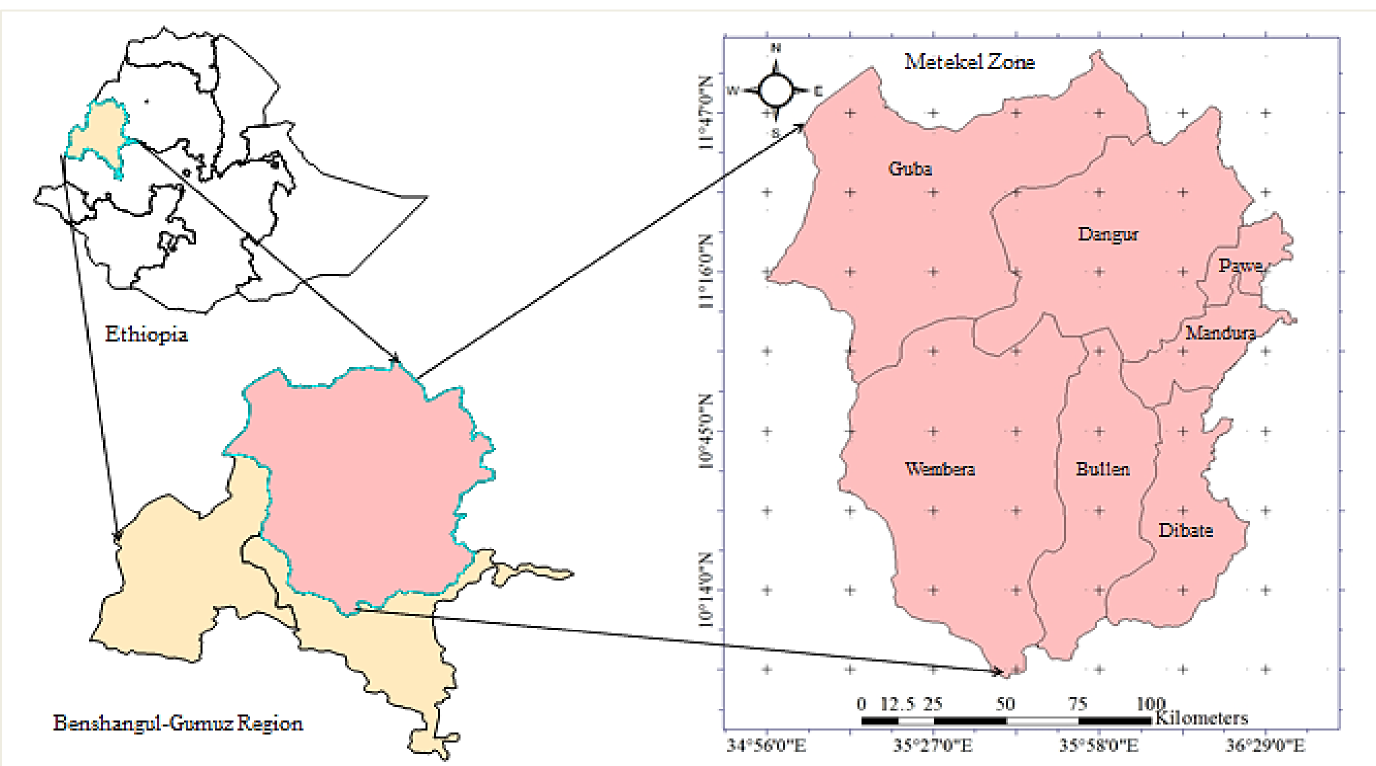


Figure 1. Location map of the study area, Metekel zone, Northwestern Ethiopia

Metekel zone is located between 9.9 to 12.5° North latitude and 34.9 to 36.6° East longitude in Benishangul-Gumuz Regional State, Ethiopia (Figure 1). It is located at a distance of about 578 Km from Addis Ababa in Northwestern direction. There are seven districts in the zone: Dangur, Guba, Wembera, Mandura, Dibate, Bulen, and Pawe.

Except Guba and Wembera, all Districts in the zone were considered in this study. The total area of the Zone estimated to be 3,387,817 ha.

The area has a uni-modal rainfall pattern with high rainfall that extends from May to October with an annual average precipitation of 1200 mm. The mean annual minimum and maximum temperatures of the area are 23 and 31.1 °C, respectively. About 80 % of the zone is characterized by having sub-humid and humid tropical climate. The topography of the study area is undulating hills slightly sloping down to low land Plateaus. The elevation ranges from 600-2800 meter above sea level (Engda, 2000). The dominant vegetation cover of the study area is characterized by different types of woodland which include broad-leaved deciduous woodland, Acacia woodland, riparian woodland along the major rivers, Boswellia woodland and bamboo thicket (UNDP/ECA, 1998).

2. 2. Site Selection, Experimental Design and Procedure

On-farm trials were made on P fertilization of maize (*Zea mays* L.) grown at 35 experimental sites over five Districts of Metekel zone (Pawe, Dangur, Mandura, Dibate and Bullen) during 2009, 2010 and 2011 cropping seasons. From each district, representative farmer fields were selected using systematic random sampling. At least 5 km distance between each selected fields was maintained during site selection at each Districts. Fields infested with *Striga*, with recent history of manure, compost, fertilizer application and slope greater than 10% were excluded from use in this study. Each experimental site included six levels of P treatments at 0, 10, 20, 30, 40 and 50 kg P ha^{-1} in the form of triple super phosphate (0, 46, 0). The treatments were replicated three times in a completely randomized block design (RCBD). A basal dose of nitrogen at 69 kg N ha^{-1} in the form of urea (46, 0, 0) was applied to each treatment to avoid N limitation.

Conventional tillage (farmers practice) for land preparation was used at all experimental sites. Seeds of maize were sowed during early June to late June at a seed rate of 30 kg ha^{-1}. Hybrid maize variety, BH-540, which is already recommended for the areas was used for this study. Planting was made by sowing two seeds per hill and after two weeks of emergence, plants were tinned to one plant per hill. The size of each treatment plots was 3.75 × 5.1 m^2 consisting of five rows per plot (3 harvestable and 2 boarder rows). The plant spacing was 75 cm and 30 cm between rows and plants, respectively. Phosphorus fertilizer and half of nitrogen were drilled into the soil along furrows at planting and mixed with soil to avoid direct contact with seeds.

The remaining nitrogen was applied during knee height growth stage of the crop by banding along the row at a distance of about 10 cm below and 5 cm a side plants. Weeds were controlled manually and relevant data were collected during the crop growing period. At maturity, harvestable rows from each treatment plots were hand harvested to determine grain yield.

2. 3. Soil Sampling, Preparation and Laboratory Analysis

Composite soil samples at 0-30 cm depth from each site were collected just before land preparation and used to characterize the soils of each sites. In addition to this, composite soil samples were collected three weeks after planting from each treatment for the determination of extractable P using bray II (0.03N NH_4F + 0.1N HCl), Olsen (0.5N $NaHCO_3$, pH 8.5) and Mehlich III (0.2N CH_3COOH + 0.013N HNO_3 + 0.015N NH_4F + 0.25N NH_4NO_3 + 0.001M

EDTA) extraction methods. The soil samples collected were air dried, crushed and passed through a 2 mm sieve for the analysis of selected soil physico-chemical properties following standard procedure. The soil analysis was carried out at the Soil Laboratory of Pawe Agricultural Research Center.

The major soil physico-chemical properties analyzed were particle size distribution (texture), pH, organic carbon (OC), total N, extractable P, cation exchange capacity (CEC), exchangeable K and Na. Soil particle size distribution was analyzed by the hydrometer method (Bouyoucos, 1962) using sodium hexametaphosphate (Calgon) as a dispersing agent. Soil textural class names were determined following the textural triangle of USDA system as described by Rowell (1994). Potentiometric method using a glass-calomel combination electrode was used to measure pH of the soils in water suspension in a 1:2.5 (soil: liquid ratio) (Van Reeuwijk, 1992). The Walkley and Black (1934) wet digestion method was used to determine soil OC content. Then, percent soil organic matter (OM) was obtained by multiplying percent soil OC by a factor of 1.724, following the assumptions that OM is composed of 58% OC. Total N was analyzed using the Kjeldhal digestion, distillation and titration method as described by Blake (1965). Extractable P was determined using the standard Bray-II (Bray and Kurtz, 1945) and Olsen (Olsen *et al*., 1954) extraction methods. Exchangeable K and Na were determined after extracting the soil samples by ammonium acetate (1N NH_4OAc) solution at pH 7.0. Exchangeable K and Na in the extract were measured by using flame photometer as described by Rowell (1994). The CEC was determined from the same soil that was leached with ammonium acetate through distillation and titration of ammonia, after washing down of excess ammonium acetate by ethyl alcohol as described by Okalebo *et al*. (2002).

2. 4. Determination of Critical Level of Extractable P Concentration

The critical level of extractable P concentration for each soil test extractant was determined by using Cate-Nelson graphical method (Cate and Nelson, 1965). The Cate-Nelson method is to plot the relative yield (0-100%) of maize against the level of extractable P in the soil (tested after three weeks of planting), where soil P-values were put on the x-axis and relative yield values (Relative grain yield (%) = yield/ maximum yield *100) on the y-axis, and scatter points were divided in to two populations with positioning the horizontal and vertical lines to maximize the number of points in the positive quadrants and minimize the number in the negative quadrants. It was divided according to the probability (high or low) that maize will respond to fertilization. Then, the soil- test value where the vertical line crosses the x-axis is selected as the soil critical level of extractable P concentration for maize.

2. 5. Statistical Analysis

The effect of P treatments on maize yield and three weeks after planting soil test P was evaluated by analyses of variance (ANOVA), using the statistical analysis system version 9.1 (SAS, 2004) software. Fisher's least significant difference (LSD) test at 5% levels of significance was used to separate the treatment means. To select the better extractant, correlation analysis among soil P extractants and between relative grain yield and soil P extractants were determined by SAS software. The mean soil analytical results of the study sites were interpreted as very low, low, medium, high and very high using standard ratings.

3. RESULTS AND DISCUSSION

3. 1. Initial Soil Physico-chemical Properties of the Experimental Sites

Summary of some selected soil physico-chemical properties of all experimental sites are presented below Table 1. The mean textural class of the study sites is categorized as clay. The mean soil PH was under the range of moderately acidic reaction classes (5.3-5.9) and considered to be satisfactory range for most crops (Tekalign, 1991). The low pH values could be due to the high mean annual rainfall (1200 mm) in the study area that results in loss of base forming cations through leaching and enhancing the activity of Al^{3+} and H^{+} in the soil solution, which reduces soil pH and thereby increases soil acidity. The mean values of OM (4.2 %) and total N (0.15 %) were under the range of medium (2.59 - 5.17 %) and high (0.12 - 0.25 %) status, respectively, according to ratings developed by Tekalign (1991). The contents of extractable P extracted by the Bray II and Olsen methods were far below 15 mg kg^{-1} of soil indicating that the soils are low in extractable P (Landon, 1991). The very low extractable P status in the soils of the study area is illustrative of P deficiency. The low contents of extractable P observed are in agreement with the results reported by Murphy (1968).

Table 1. Summary of soil chemical and physical properties of soils in 35 studied on farm sites.

Soil properties	Mean	Range
Clay (%)	61	83-26
Silt (%)	20	36-10
Sand (%)	19	56-2
Texture	Clay	---
pH	5.76	5.06-6.58
OM (%)	4.20	2.99-6.92
Total N (%)	0.15	0.10-0.21
C: N ratio	16.5	11.0-22.1
Bray II- extractable P (mg kg^{-1} of soil)	4.90	0.74-21.71
Olsen-extractable P (mg kg^{-1} of soil)	3.23	0.86-10.37
CEC ($cmol_{(+)}$ kg^{-1} of soil)	26.7	12.3-37.4
Exchangeable K ($cmol_{(+)}$ kg^{-1} of soil)	0.50	0.15-1.36
Exchangeable Na ($cmol_{(+)}$ kg^{-1} of soil)	0.14	0.05-0.26

The mean CEC value, 26.7 $cmol_{(+)}$ kg^{-1} of soil, of the soils are categorized at a high level (> 25 $cmol_{(+)}$ kg^{-1} of soil) (Landon, 1991). The high values of CEC offer high buffering capacity against induced changes to the soil as described by Mohammed *et al*. (2005). The mean exchangeable K status of the soils (0.50 $cmol_{(+)}$ kg^{-1} of soil) was categorized under the range of medium (0.3 - 0.6 $cmol_{(+)}$ kg^{-1} of soil) according to FAO 2006a rating, indicating that the content of exchangeable K of the study sites is above the threshold level (0.38 $cmol_{(+)}$ kg^{-1} of soil) for most crops for K fertilizer requirement (Barber, 1984). This indicated that K status of the studied sites could be sufficient for optimum crop production. The soils of the studied sites were generally low in Na content as per the rating suggested by FAO (2006a). Apparently, this is due to the high amount of annual rainfall at the study area which causes leaching of basic cations.

3. 2. Response to P Fertilizer Application

The three years individually and combined analysis of variance of all 35 site- years indicated that there were significant ($P < 0.05$) responses of grain yield to P fertilizer rates (Table 2). Similarly, extractable P concentration extracted after three weeks of planting by using three extraction methods were also significantly differed ($P < 0.05$) among P fertilizer rates (Table 3). Considering the combined analysis, the highest maize grain yield (5256.2 kg ha^{-1}) was recorded from the application 40 kg P ha^{-1}. Compared to the control, grain yield increased 19.8 %, 29.3%, 32.4%, 35.6% and 35.3%, by applications of 10, 20, 30, 40 and 50 kg P ha^{-1}, respectively. Maize grain yield recorded from the application of 20 kg P ha^{-1} was significantly highest than the control and 10 kg P ha^{-1} application, whereas higher P application rates above 20 kg ha^{-1} did not result in significantly higher grain yield even though yield increase was observed up to P fertilizer rate of 40 kg P ha^{-1}. Application of 50 kg P ha^{-1}, however, reduced the grain yield as compared to the preceding treatment. The result indicated that application of 20 kg P ha^{-1} could be sufficient for optimum maize grain yield production in the study area. Similarly, Yihenew (2016) also reported a significant ($P <$ 0.05) maize yield increase due to P application in acidic Alfisols of Northwestern Ethiopia. The author also indicated that increasing the P rate only up to 13 kg P ha^{-1} gave a significant grain yield increase over the control and application beyond did not bring profitable yield increase.

Table 2. Maize grain yield response to P fertilizer rates.

P rates (kg ha^{-1})	**Maize grain yield (kg ha^{-1})**			
	2009	2010	2011	Combined
0	4160.0^{c}	3781.2^{c}	3671.8^{c}	3876.7^{c}
10	5173.4^{b}	4504.0^{b}	4219.5^{bc}	4644.1^{b}
20	5715.2^{ba}	4765.8^{ba}	4509.4^{ba}	5010.7^{a}
30	5671.5^{ba}	5168.9^{a}	4504.1^{ba}	5132.2^{a}
40	5797.3^{a}	5130.2^{a}	4803.5^{a}	5256.2^{a}

50	5865.9[a]	5028.6[ba]	4798.2[ba]	5243.3[a]
LSD (0.05)	586.3	579.7	550.1	328.4
CV (%)	23.4	26.4	25.6	24.9

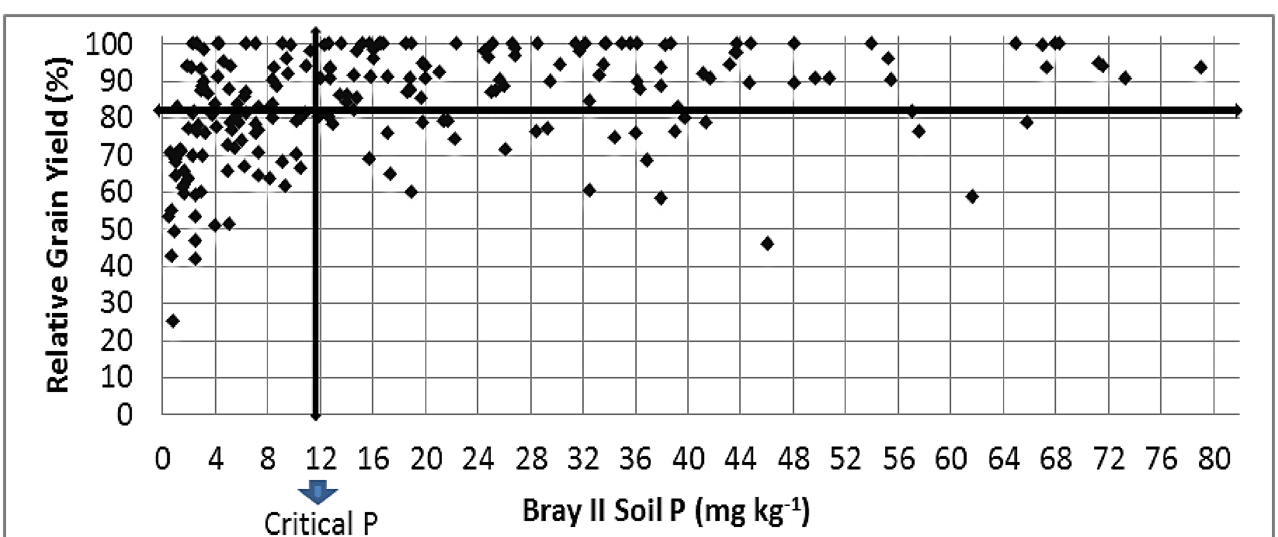
Means within a column followed by same letters in superscripts are not significantly different from each other at P > 0.05.

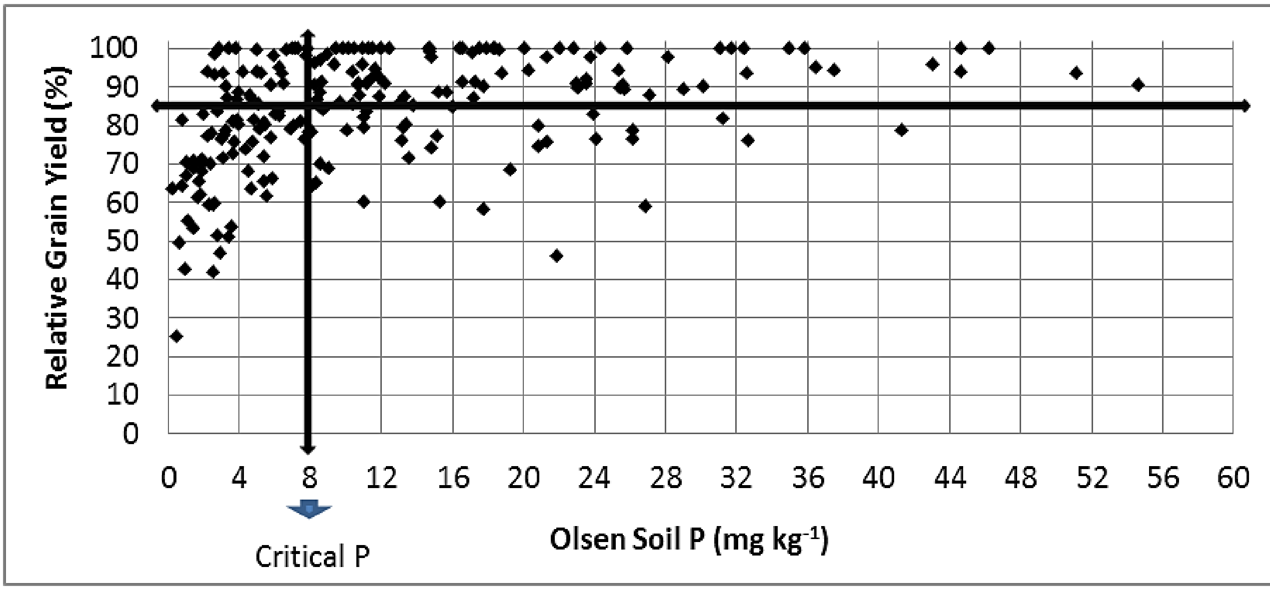
3. 3. Critical Level of Phosphorous

The critical level of extractable P concentration for maize, using all site-years data of soil test P and corresponding relative grain yield for all treatments, tested by three extraction methods were determined by Cate-Nelson graphical method as shown in the figure below. The result revealed that the critical levels of extractable P were 12, 8 and 10 mg kg^{-1} soil for bray II, Olsen and Mehlich III extraction methods, respectively. Therefore, at values less than these critical levels of extractable P, P fertilizer should be applied to increase maize yield. Conversely, phosphorous fertilizer application is not likely to increase grain yield of maize at soil P concentration above the critical level.

Comparable critical values of P have been reported in literature. For example, Tekalign and Hague (1991) have shown the critical Olsen P values to be 8 mg kg^{-1} for Ethiopian soils. Taye *et al*. (2000) reported that 10 mg kg^{-1} to be the critical Olsen P level for wheat in soils of Hitosa Woreda, Ethiopia. Very recently, Yihenew (2016) reported that the soil P critical level measured by Bray II extraction method for maize was 14.6 mg kg^{-1} soil in Alfisols of Northwestern Ethiopia.

Similarly, Getachew and Berhane (2015) also reported that the critical level of extractable P using Bray II method for malt barely was 12 mg kg^{-1} in Nitisols of Ethiopian highlands. They also indicated that the level beyond the critical level, an economic response by malt-barely could not be expected.





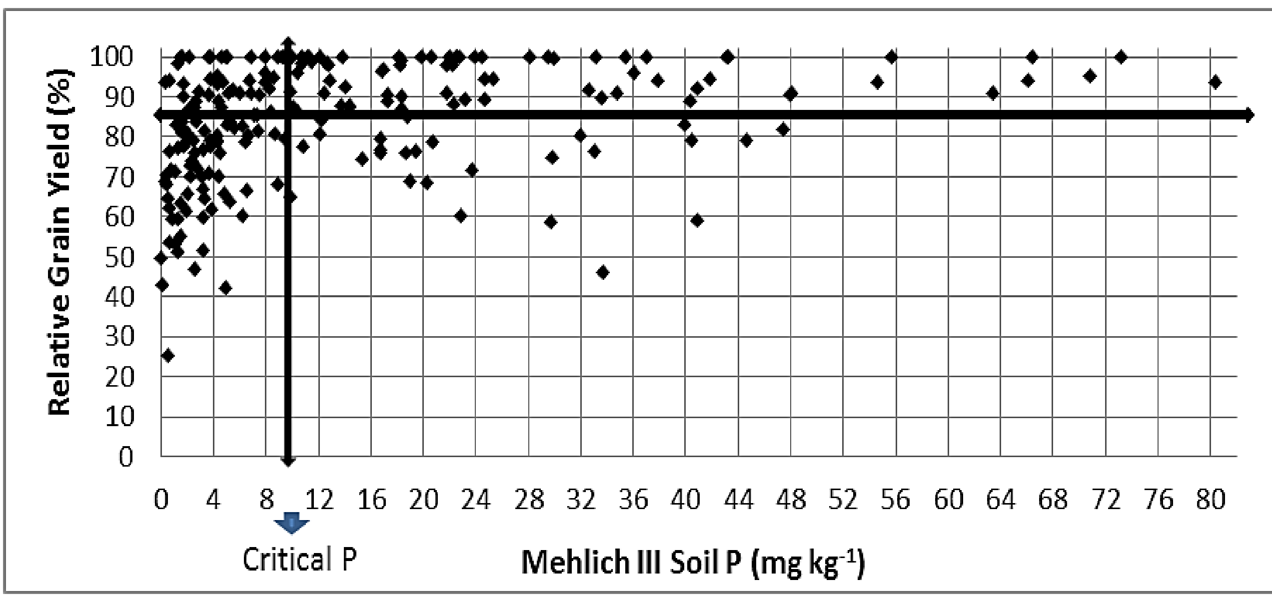


Figure 2. Critical level of extractable P concentration using three P extraction methods (Bray II, Olsen and Mehlich III) as determined by Cate-Nelson graphical method.

3. 4. Evaluation of P extractants

Extractable P by the Bray II, Olsen and Mehlich III methods in this study were correlated among themselves (Table 4). The coefficient of determination (r) varied from 0.88 to 0.94 indicating that any of these extractants can be used to estimate P extractability.

However, there was difference among the methods in extracting the quantity of P. The quantities of P extracted by the three extractants were in the following order: Bray II > Mehlich III > Olsen P extraction method (Table 3).

Moreover, as presented in Table 4, the correlation coefficients revealed that relative grain yield was positively and significantly correlated with P extracted from soil using Bray II (r = 0.38), Olsen (r = 0.35) and Mehlich III (r = 0.32) extraction methods indicating that Bray II P had showed the highest correlation with relative grain yield than the other methods. Therefore, Bray II extractant can be considered as suitable extractant for the determination of extractable P for soils of the studied area.

Table 3. Three weeks after planting mean soil test P using three extraction methods with respect to P rates and response to P fertilizer rates.

P rates (kg ha^{-1})	**Soil test P (mg kg^{-1})**		
	Bray II	Olsen	Mehlich III
0	4.41^{d}	3.28^{d}	3.08^{d}
10	9.08^{d}	6.03^{d}	6.25^{d}
20	17.20^{c}	10.33^{c}	11.70^{c}
30	24.80^{b}	15.28^{b}	17.35^{b}
40	28.31^{b}	18.06^{b}	20.43^{b}
50	37.03^{a}	23.00^{a}	28.42^{a}
Mean	20.14	12.66	14.54
LSD (0.05)	5.52	3.21	5.05

Means within a column followed by same letters in superscripts are not significantly different from each other at $P > 0.05$.

Table 4. Pearson's correlation matrix among soil P extractants and between relative grain yield and soil P extractants.

	Bray II	**Olsen**	**Mehlich III**	**Relative grain yield**
Bray II	1			
Olsen	0.92**	1		
Mehlich III	0.94**	0.88**	1	
Relative grain yield	0.38**	0.35**	0.32*	1

**Significant at $P < 0.01$; * significant at $P < 0.05$

4. CONCLUSION

Grain yield of maize responded positively and significantly to P fertilizer application of the study area. Similarly, extractable P concentration extracted after three weeks of planting by using three extraction methods were also significantly differed among P fertilizer rates. Using the Cate and Nelson graphical method, the critical levels of soil extractable P concentration for maize production were 12, 8 and 10 mg P kg^{-1} soil for Bray II, Olsen and Mehilich III extraction methods, respectively for the study area. Results shows that at values less than these critical levels of extractable P, P fertilizers should be applied to increase maize yield. The P concentrations extracted by Bray II P was more correlated (r = 0.38) with relative maize grain yield than and Olsen and Mehlich III extraction methods. In addition, Bray II extraction method was better in extracting more extractable P from the soil indicating that that Bray II was found to be the most suitable P extraction method in the study area.

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