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# Soil test crop response based phosphorus calibration study for bread wheat in Kofele District, West Arsi Zone Oromia, Ethiopia

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## ABSTRACT

Nowadays, a balanced fertilizer recommendation is of paramount importance in order to confirm the security and sustainably increase crop productivity for farmers and other stakeholders. Soil test crop response based phosphorus calibration study in two years (2017 and 2018) was done for bread wheat in kofele district with objectives to assess and evaluate yield response of bread wheat to phosphorus-fertilizer applications in soils that have initial high/medium/low levels of phosphorus on Eutric Vertisols. A composite soil samples collection were made in zigzag method from farmer's land and analyzed for available P in order to identify the level of the required parameters in the soil to select farmland for actual experiment. Accordingly, phosphorus calibration study treatments include application of 0, 10,20,30,40 and 50 kg P ha<sup>-1</sup> with recommended nitrogen 69 kg N ha<sup>-1</sup> with RCBD design was used with two replications. The plot size of 5m x 4m with a seed rate of 150 kg ha<sup>-1</sup> and Ogolcho variety which had been recommended for the area was used. So that the result showed that phosphorus fertilizer application significantly affects yield and yield components of bread wheat. Similarly, phosphorous fertilizer application at different rates increased grain yield of bread wheat by 28 to 44% compared to the control. Furthermore, the study was revealed that phosphorus critical (P<sub>c</sub>) point for bread wheat was 19, and phosphorus requirement factor was also 3.30. Therefore, future research should focus on verification of the result on farmland before disseminating the technology to the end-user.

**KEYWORDS:** Calibration, Phosphorus, Soil test, Concentration, Application and Available

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## INTRODUCTION

Wheat (*Triticum spp.*) is one of the world's most important staple foods for about one third of the world's population (Hussain *et al.*, 2006). Among many wheat plants, only three species are commercially important. These are bread wheat (*Triticum aestivum*), durum wheat (*Triticum durum*) and emmer wheat (*Triticum compactum*) (Gooding and Davies, 1997). Ethiopia is the second-largest producer of wheat in sub-Saharan Africa with an estimated area of 1.6 million ha (CSA, 2015). However, the Ethiopian government is forced to import wheat every year because of higher demand than supply and low productivity (World Fact Book, 2012). Chemical fertilizers are expensive to purchase and especially, it is the great problem for most small-scale farmers (Zelege *et al.*, 2010; Agegnehu & Amede, 2017). Hence, phosphorous is the most yield limiting of soil supplied elements and soil P tends to decline when soils are used for agriculture (Edelstein & Tonjes, 2012). In Ethiopia, the blanket recommendations that are presently in use all over the country were issued several years ago, which may not be

suitable for the current production systems (Zelege *et al.*, 2010). Since the spatial and temporal fertility variations in soils were not considered, farmers have been applying the same P fertilizer rate to their fields regardless of soil fertility differences. For these reasons, the blanket recommendation will make inefficient use of these expensive nutrients, which contribute to the depletion of scarce financial resources, increased production costs and potential environmental risks (Tarekegne & Douglas, 2001).

Effect of phosphorus fertilizers on yield which was increased significantly from 1761 to 2300 kg ha<sup>-1</sup> with an increase in the level of P fertilizer from the control to 46 kg ha<sup>-1</sup>. Likewise, the magnitude of increase in grain yield due to the application of 46 kg ha<sup>-1</sup> of phosphorus was 30.6 % higher as compared to the control (Getahun *et al.*, 2018). Phosphorus calibration is a means of establishing a relationship between a given soil test value and the yield response from adding nutrients to the soil as fertilizer. Likewise, it provides information on how many nutrients should be applied at a particular soil test value to optimize crop growth without excessive waste and confirm the

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validity of current P recommendations (Agegnehu *et al.*, 2015). Sound soil test based and site specific nutrient management is essential in reversing this trend and increase crop yield in agricultural land. Results of soil tests must be calibrated against crop response from applications of the plant nutrients in question (Wortmann, 2015). Calibration research predicts the probability of response from applying a given nutrient which must be determined experimentally in the field (Dahnke and Olsen, 1990). Calibrations are specific for each crop type, soil type, soil pH, climate plant species, and crop variety (Self, 2013; Agegneh & Lakew, 2013). Currently, soil fertility research improvement is geared towards site specific fertilizer recommendation. Therefore, the establishment of a reliable soil test can assist in the determination of P requirements. Moreover, It involves a correlation to find an extracting for soil nutrients for a laboratory test that was the best mine an amount of a nutrient proportional to what a plant extracts (Seif, 2013). Therefore, the objectives of this study were to determine bread wheat yield response to P, the critical P concentration, P requirement factor and establish an agronomic recommendation for fertilizer rate on bread wheat yield.

## MATERIALS AND METHODS

### Descriptions of Study Area

Phosphorous calibration trials with bread wheat were conducted on farmers' fields from 2017 & 2018 during the main cropping seasons at Kofole district, West Arsi zone, in the central highlands of Ethiopia (Figure 1). Bread wheat is grown mainly by subsistence farmers in the study area, which is located at 06° 50' to 07° 09' N and 38°38' to 39°04' E at a distance of about 280 km Southeast of Addis Ababa and at an altitude of 2620 m above sea level. According to National Ethiopia Meteorology agency Station

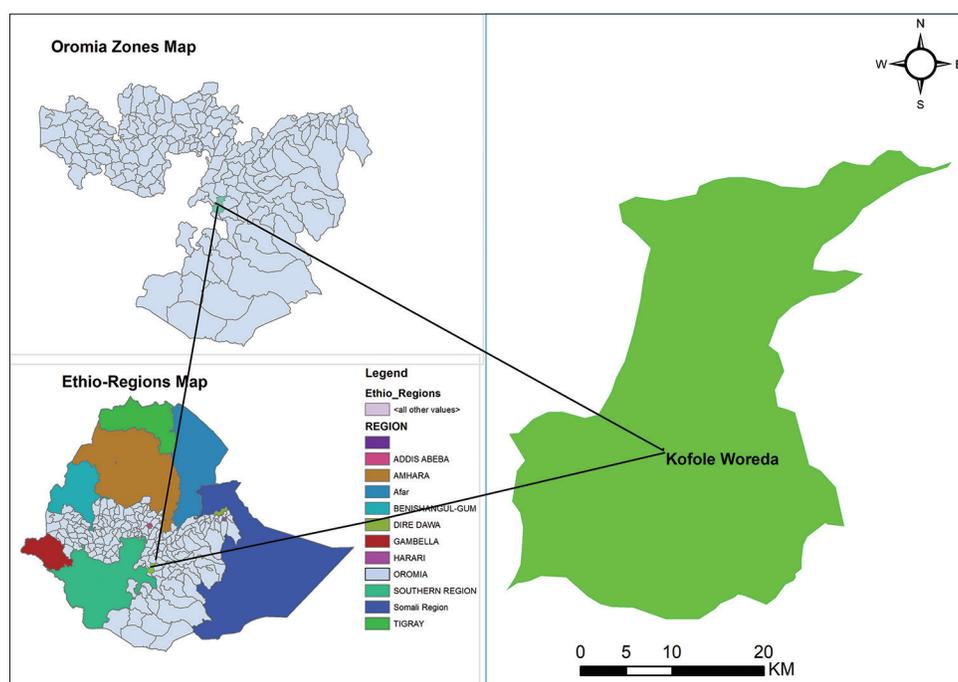
records from the experimental field was under continuous cereal production for long time. The area is characterized by high altitude in the humid temperate climatic zones. The long-term (1998-2018) mean total annual rainfall is 1036 mm with mean maximum and minimum temperatures of 19.64 and 7.53°C, respectively (Figure 1). The environment is seasonally humid and major soil type of the trial sites is Eutric Vertisols. The coldest month is July whereas March is the hottest month.

### Experimental Setup

The design used was a random complete block design with two replications. On the other hand, during main calibration a composite soil samples were collected from farmer fields before planting i.e. 20-30 sub samples with 0-20cm depth by zigzag method. So that available phosphorus was analyzed using Olsen *et al.* (1954) method. Accordingly the value of soil test ranged from very low to very high, while a total of 22 farmers land with low, medium and high P soils were selected as test sites in the two main experimental years. Based on the level of P content, 12 and 10 farmlands were selected during the first and second years, respectively for phosphorus calibration. The treatments were included the application of 0, 10, 20, 30, 40, and 50 kg ha<sup>-1</sup> of phosphorus with optimum N determined for all treatments and RCBD design with two replications. The plots size was 4mx5m and Ogocho variety was used at a seed rate of 150 kg ha<sup>-1</sup>. Other practices like hand weeding, herbicide application, and disease/pest protection were undertaken according to the recommendations for the locality and/or farmers practice.

### Determination of Critical Phosphorus Concentration (P<sub>c</sub>)

To correlate relative yield vs. soil test P values and to determine critical P concentration, the available P was extracted from the



**Figure 1:** Maps of the study area

soil samples taken three weeks after planting from each plot of all experimental (including all replication) fields using Olsen method. The Cate-Nelson graphical method (Nelson and Anderson, 1977) was used to determine the critical P value using relative yields and soil test P values obtained from 18 P fertilizer trials conducted at different sites, 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:  $\text{Relative yield} = \text{Yield}/\text{maximum yield} \times 100$ .

The scatter diagram of the relative yield (Y-axis) versus soil test value (X-axis) was plotted. The range in values on the Y-axis was 0 to 100%. A pair of intersecting perpendicular line 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 quadrant overestimate the P fertilizer 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 (Nelson and Anderson, 1977).

Determination of Phosphorus requirement factor (Pf) is the amount of P in kg needed to raise the soil P by  $1 \text{ mg kg}^{-1}$ . It enables to determine the quantity of P required per hectare to raise the soil test by  $1 \text{ mg kg}^{-1}$ , and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level (Nelson and Anderson, 1977). It was calculated using available P values in samples collected from unfertilized and fertilized plots. Phosphorous requirement factor was expressed as:  $\text{Pf} = \text{kg P applied} / \Delta \text{ soil P}$ . Therefore the rate of P fertilizer to be applied (Pa) was expressed in terms of critical P concentration (Pc), initial soil P value (Pi) and P requirement factor (Pf). Rate of P fertilizer to be applied =  $(\text{Pc} - \text{Po}) * \text{Pf}$  Where, Pc = critical P concentration, Po = initial P values for the site, and Pf = P-requirement factor.

In order to see the availability of P a composite soil samples were collected from representative trial sites across the treatment applied to the selected site with two years of 308 samples after 21 days of planting (0-20 cm depth). The collected soil samples were analyzed for available P using Olsen method. Likewise, like grain yield, aboveground total biomass, thousand seed weight, panicle length and plant height (average of 5 plants) were collected. Total biomass and grain yields recorded on plot basis were collected and converted to  $\text{kg ha}^{-1}$  for statistical analysis. Similarly, partial budget analysis was employed and calculates the marginal rate of return (MRR) (CIMMYT, 1988), because the treatments were significance and also economic analysis was done for optimum nitrogen fertilizer determination. Additionally, the grain yield was adjusted by 10% to reduce the exaggeration of small plot management. Moreover, all agronomic and soil data which were collected across locations was properly managed using the EXCEL computer software. The collected data were subjected to the analysis of variance using the SAS computer package version 9.0 (SAS Institute, 2002) statistical software.

## RESULTS AND DISCUSSION

Phosphorus calibration experiments had been undertaken at Kofole. Accordingly, a field experiment was designed and studied to identify bread wheat response to the applied N and P rates from 2017-2018 on twenty two (22) farmer field for determination of soil P critical, P requirement factor. So that P-critical and requirement factor determination were undertaken on twelve (12) in 2017 and ten (10) farmer's field in 2018. Similarly, six (6) sites were fell as very low available phosphorus while the other ten (10) and six (6) sites were categorized as low and medium available phosphorus respectively.

### Critical P Concentration (Pc)

The correlation between relative bread wheat grain yield response and soil P measured with Olsen method was tested in Figure 3. The increase in soil P response to P fertilizer application was linear up to  $50 \text{ kg P ha}^{-1}$ . The critical P concentration (Pc) was

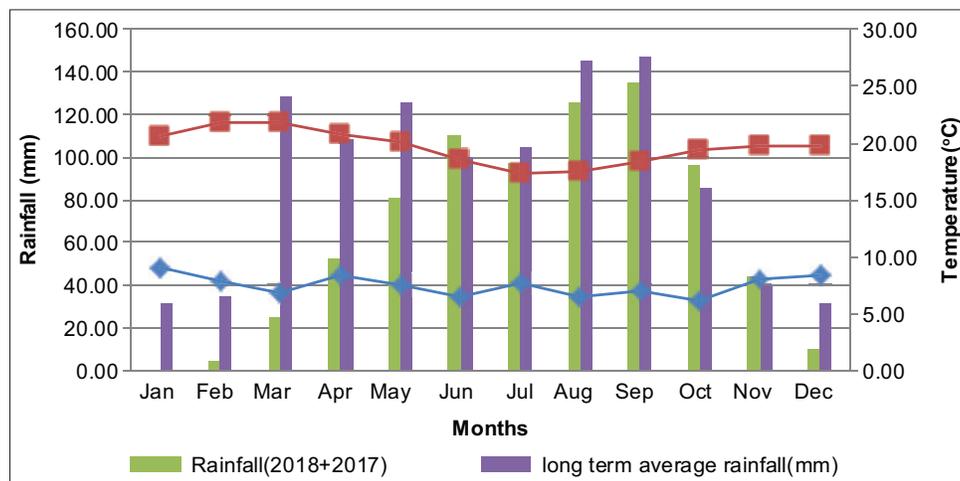
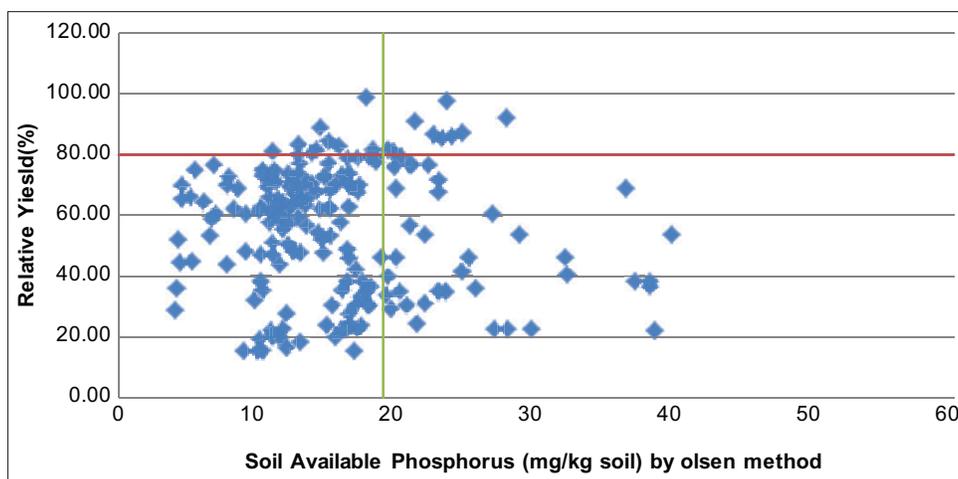


Figure 2: Monthly rainfall 2017 & 2018, long term average rainfall, maximum and minimum monthly average temperature of Kofole District



**Figure 3:** Relationships between soil extractable P measured using Olsen method and bread wheat relative yield (percentage of the maximum yield). Using the graphical method of Nelson and Anderson a critical limit of 19 mg P kg<sup>-1</sup> of soil extractable P was identified

determined from the scatter diagram drawn using relative grain yields of bread wheat and the subsequent soil test P values for all P levels (0-50 kg P ha<sup>-1</sup>). The main effect of P fertilizer resulted in mean soil test P values of 16.88 to 29.10 mg kg<sup>-1</sup>. Olsen soil test P values below 10 mg kg<sup>-1</sup> are considered low. The highest mean soil P concentration (29.10) was recorded from 50 kg P ha<sup>-1</sup> (Figure 3). The P<sub>c</sub> defined by the Cate Nelson method in this study was about 19 mg P kg<sup>-1</sup>, with mean relative yield response of about 80% (Figure 3). When the soil test value is below the critical value additional information is needed on the quantity of P required to elevate the soil P to the required level. These results in line with Getahun *et al.* (2018), correlations of relative yield with soil test phosphorous values showed that the critical soil P concentration and average phosphorous requirement factor (Pf) calculated from soil test phosphorous values of all treatments for the study area were 8.5 and 6.55 mg kg<sup>-1</sup> soil respectively for the Assosa Zone.

### P Requirement Factor (Pf)

Calculated phosphorus requirement factor (Pf), for bread wheat production on Eutric Vertisols in kofole district was 3.30 (Table 1). It is computed from the difference between available soil test P values from plots that received 0-50 kg P ha<sup>-1</sup> using the second formula mentioned above. 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. This is the P requirement factor (Pf), the amount of P required to raise the soil test P level by 1mg kg<sup>-1</sup>. Thus the rate of P fertilizer required per hectare can be calculated using the soil critical P concentration, initial soil P determined for each site before planting and the P requirement factor as indicated above in the third formula.

According to the Nelson and Anderson method, determined critical level of Olsen method in the top 20 cm of soil was about 19 mg kg<sup>-1</sup>. At values of greater than or equal to 19 mg kg<sup>-1</sup>, the crop achieved about 80% of its maximal yield in the absence of

P fertilizer application (Figure 3). This implies that P fertilizer application could be recommended for a buildup of the soil P to this critical value, or maintaining the soil P at this level. Increasing P beyond this level, the cost of additional P fertilizer to produce extra yield would likely be greater than the value of the additional yield. This study in line with Reda *et al.* (2019) the Pf computed from the difference between available P values in soil samples collected from plots, which were received 0, 23, 46, 69 and 92 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> the average value of P-requirement factor was 16.27 mg kg<sup>-1</sup>. Similarly the studies reported critical concentrations of 19 and 13 and 13.5 mg P kg<sup>-1</sup> using Bray 2 test for food barley, malting barley and wheat on Nitisols, respectively (Admassu, 2017; Agegnehu and Lakew, 2013; Agegnehu *et al.*, 2015).

### Yield and Yield Components of Bread Wheat in Responses to Phosphorus Fertilizer

The responses of yield and yield components of bread wheat to phosphorus fertilization, year and interaction of year by phosphorous of the combined data of over two years are presented in the following Table 2. The analysis of variance for two cropping year revealed that grain yield and yield components of bread wheat were significantly affected by year and P fertilizer. Likewise, the year effect was highly significant ( $P < 0.01$ ) for grain and yield components of bread wheat (Tables 3 and 4). On the other hand year and P fertilizer rate interaction was not significant for biomass, spike length and seed yield per plant. The maximum biomass yield, harvest index, seed yield, panicle length and plant height also recorded in the same cropping season. Grain yield, biomass yield, harvest index, seed yield per plant, panicle length, plant height days to 50% flowering significantly responded ( $p < 0.01$ ) to P fertilizer application rate. The application of P fertilizer rate of 10,20,30,40, and 50 kg ha<sup>-1</sup> increased grain yields of bread wheat compared to the control (without P fertilizer).

The combined analysis of variance across all experimental locations signify that bread wheat yield and yield components

**Table 1: Determination of P requirement factor (Pf) for bread wheat in kofole district**

Phosphorus Rate kg/ha	Soil Test P mg/kg (Olsen Method)		p-increases over contro	Pf
	Range	Average		
0	3.14-30.61	16.88		
10	4.74-38.04	21.39	4.52	2.21
20	5.04-41.75	23.40	6.52	3.07
30	5.27-45.01	25.14	8.27	3.63
40	6.42-50.21	28.32	11.44	3.50
50	6.80-51.40	29.10	12.23	4.09
				3.30

**Table 2: Effects of years, P fertilizer rates and their interaction (YxP) on yield and yield components of bread wheat across sites in 2017 and 2018**

Parameters	Year (Y)	Phosphorous (P)	YxP
Grain Yields (Qu/ha)	***	***	**
Biomass (ton/ha)	***	***	NS
Harvest Index (%)	**	**	**
Plant Height (cm)	***	***	**
Seed/spike	**	NS	NS
Spike length (cm)	***	***	NS

\*\*\* is highly significant, \*\* is significant and NS is not significant different

**Table 3: Means for main effects of P application years and fertilizers rate on bread wheat yield in 2017 and 2018**

Factor	Biomass (ton/ha)	Grain Yields (Qu/ha)	Harvest Index (%)
0	9.48 <sup>d</sup>	31.54 <sup>d</sup>	32.57 <sup>c</sup>
10	12.33 <sup>bc</sup>	43.53 <sup>bc</sup>	34.62 <sup>abc</sup>
20	13.43 <sup>abc</sup>	47.19 <sup>bc</sup>	34.85 <sup>abc</sup>
30	13.90 <sup>abc</sup>	49.84 <sup>ab</sup>	35.40 <sup>ab</sup>
40	14.00 <sup>ab</sup>	50.15 <sup>ab</sup>	36.40 <sup>a</sup>
50	15.49 <sup>a</sup>	56.19 <sup>a</sup>	36.49 <sup>a</sup>
LSD (0.05)	2.08	7.81	2.74
CV (%)	34.71	36.84	16.97

Means followed by the same letter within the same column of the respective treatment are not significantly different ( $P \leq 0.05$ ), CV = Coefficient of variation, LSD = Least Significant differences, NS = not significant

**Table 4: Means for main effects of P application years and fertilizers rate on bread wheat yield related parameters in 2017 and 2018**

Factor	Plant height (cm)	Seed/Spike	Spike length (cm)
0	89.19 <sup>c</sup>	48.10 <sup>c</sup>	7.30 <sup>b</sup>
10	95.70 <sup>ab</sup>	53.51 <sup>ab</sup>	7.91 <sup>a</sup>
20	97.55 <sup>a</sup>	53.49 <sup>ab</sup>	7.99 <sup>a</sup>
30	98.52 <sup>a</sup>	53.34 <sup>ab</sup>	8.03 <sup>a</sup>
40	98.68 <sup>a</sup>	53.84 <sup>ab</sup>	7.90 <sup>a</sup>
50	99.51 <sup>a</sup>	54.99 <sup>a</sup>	8.09 <sup>a</sup>
LSD (0.05)	3.91	2.94	0.31
CV (%)	8.77	12.02	8.58

Means followed by the same letter within the same column of the respective treatment are not significantly different ( $P \leq 0.05$ ), CV = Coefficient of variation, LSD = Least Significant differences, NS = not significant

differed significantly ( $P < 0.01$ ) among trial locations. Similarly, according to Admassu (2017) the analysis of variance grain

yield and yield components of tef were significantly affected by year and P fertilizer. These results are in general in accordance with the results of several studies, which showed the positive response of bread grain yield and other cereals to phosphorous fertilization in Ethiopian highland areas (Admassu, 2017; Agegnehu *et al.*, 2015; Balcha, 2014). Additionally, Admassu (2017) also stated the importance of soil test based P fertilizer application for improving yield and yield components of tef on Ethiopian central highlands soils. On the other hand, the application of P was not significant on plant height; straw yield and grain yield in Lume whereas the interaction effect of N and P application on grain yield, plant height and straw yield correlation was significant (Assefa *et al.*, 2017).

Means followed by the same letter within the same column of the respective treatment are not significantly different ( $P \leq 0.05$ ), CV = Coefficient of variation, LSD = Least Significant differences, NS = not significant

## CONCLUSION AND RECOMMENDATIONS

Phosphorus calibration study had been conducted on bread wheat for one year (2016) as optimum nitrogen determination and two years (2017-2018) growing season for phosphorus critical and requirement factors in Kofole district. Accordingly, as the results of field work clearly revealed the importance of soil test based P fertilizer application for improving yield and yield components of bread wheat on Eutric Vertisols of the district. Likewise, critical P ( $P_c$ ) concentrations (19 ppm) and P (Pf) requirement factors (3.30) for bread wheat were determined. Furthermore, a successful fertilizer recommendation program depending on the results of soil test crop response based calibration study which is conditional on rainfall and soil moisture status which influences the response of crops and yield to a greater extent than fertilizer applications. Further verification of the result on farm land could be a pre request before disseminating the technology to the user.

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