

# Soil Test Crop Response Based Phosphorus Calibration Study for Bread Wheat in Shashemene District of West Arsi Zone, Oromia, Ethiopia

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## Abstract

Soil test based crop response phosphorous calibration study was conducted Shashemene district on bread Wheat crop during the main cropping season of 2018 -2020 with the objectives to determine  $P_c$  and  $P_f$  for bread wheat crop, and to establish site-specific soil test based phosphorus fertilizer recommendation. RCBD design was used with 3 replication using 5 rates of N (0, 46,69 and 92 kg ha<sup>-1</sup>) and 5 rates of P (0, 10, 20, 30 and 40 Kg ha<sup>-1</sup>) in a factorial combination to determine optimum level of N- rate for bread wheat crop production. In the second and third year 5 levels of P (0, 10, 20, 30, and 40 Kg ha<sup>-1</sup>) and 46 kg N ha<sup>-1</sup> of optimum nitrogen rate obtained were applied uniformly for all plots to determine P-critical value ( $P_c$ ) and P-requirement factor ( $P_f$ ) for bread Wheat. A total of experimental plot size 3m\*3m (9 m<sup>2</sup>) and Seeds rate of 150 kg ha<sup>-1</sup>. Composite Surface soil samples from 0-20 cm depth were collected from each experimental plot before planting. Similarly, after 21 days of planting, composite soil samples were taken at (0-20 cm depth) using auger from each plot for analysis of available p using Olsen method. The result of the study showed that low to extremely high available P ranged from 7.7-56ppm. The mean maximum grain yield (5358kg/ha) was obtained from the application of 46 kg N /ha and 92 kg P<sub>2</sub>O<sub>5</sub> /ha whereas the lowest (1873kg /ha) was obtained from control treatment. On the other hand, the combination of 69kg N/ha and 92kg P<sub>2</sub>O<sub>5</sub>/ha could result the highest net benefit of 114425.00 birr per hectare. However, 46 N kg ha<sup>-1</sup> N fertilizers was determined as economically feasible optimum N rates at 2655%, MRR on Eutric andosol in Shashemene district for Bread wheat. From phosphorous calibration study, P-critical value (21 ppm) and P-requirement factor (4.43) was determined for phosphorus fertilizer recommendation for bread wheat crop production in the area. Therefore, the obtained result has to be verified and the economic benefit must be studied across farmers' fields.

**Keywords:** Calibration, Phosphorous, Soil Test, West Arsi, Bread wheat

**DOI:** 10.7176/JBAH/11-10-01

**Publication date:** May 31<sup>st</sup> 2021

## 1. Introduction

The population of Ethiopia is currently growing at a faster rate and demands an increased proportion of agricultural products. On the other hand, growth in food production is not in equal footings with population pressure. Strengthening food production capability of the country by wisely exploiting its existing human and natural resources is critical option to avert the existing situation. 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, 2004). 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., 2002). The identification of the proper fertilizer mix is beneficial at the macroeconomic level by 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. But, if harvested nutrients are replaced, intensive agricultural systems can be sustained indefinitely, provided that measures are taken to halt soil erosion and to minimize detrimental changes in soil pH.

Fertilizer use in Ethiopia has focused mainly on the use and application of nitrogen and phosphorous fertilizers in the form of NPS and urea for almost all cultivated crops for both market and food security purposes for the last several years. Such unbalanced application of plant nutrients may aggravate the depletion of other important nutrient elements in soils such as K, Mg, Ca, S and micro-nutrients. Though, nitrogen, phosphorus and potassium are the three major nutrient elements required in large quantities for normal growth and development of crops, some nutrient elements such as potassium are not being used as a commercial fertilizer for agricultural crop production under Ethiopian conditions (Abiye et al., 2004; Asegil et al., 2007).

Nitrogen and phosphorus are the most yield limiting nutrients in Ethiopia. The use of chemical fertilizer to overcome these nutrient deficiencies is a practice that is receiving a wide acceptance in the country. Some attempts were made in the past to relate soil test data to crop performance and yields but were not successful mainly due to inappropriate design used, inadequate sampling intensity and high level of variability in soil test data (Holeta Genet progress report, 1973/74 and 1975/76). Soil test based fertilizer recommendation plays a

vital role in ensuring balanced nutrition to crops. 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. Calibrations are specific for each crop type and they may also differ by soil type, climate, and the crop variety (Alem et al., 2008; Fufa and Hassen 2005).

Therefore, fertilizer application schedules should be based on the magnitude of crop response to applied nutrients at different soil fertility levels (Wassie *et al.*, 2011). Like other regions of the country, a fertilizer recommendation for wheat in shashemene district is also not based on soil test results.

**1. Therefore, the objective of this study was:**

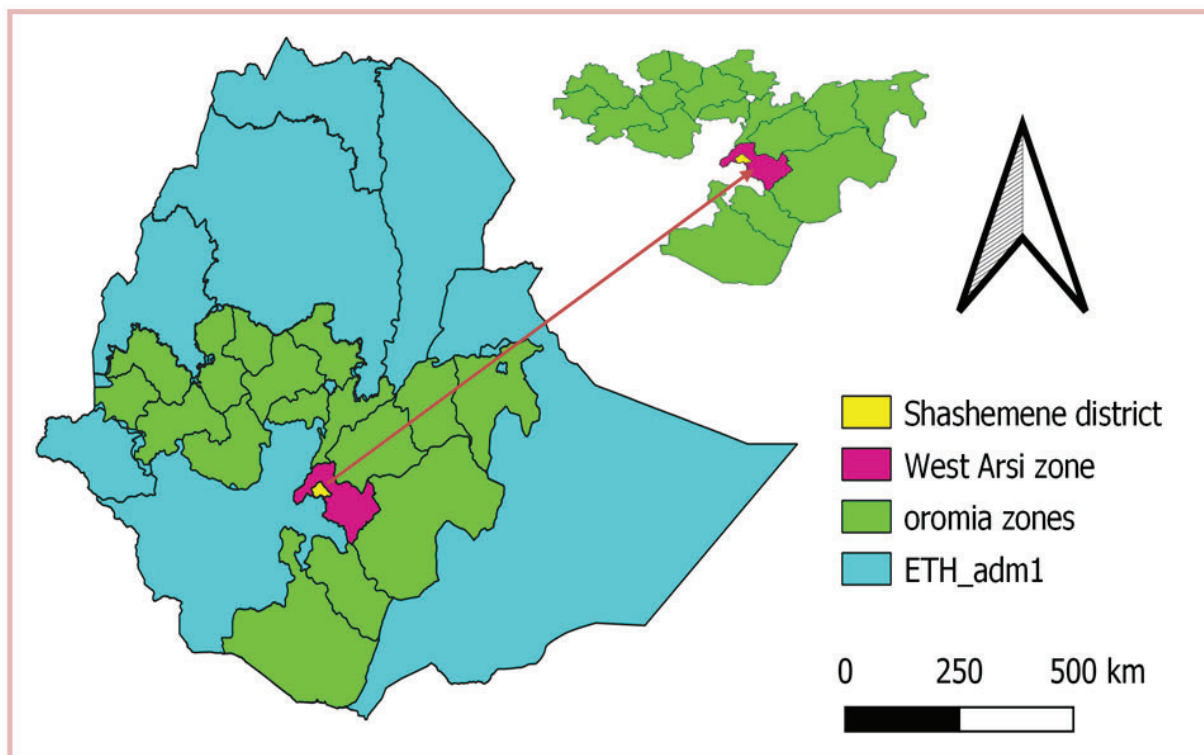
- a) To determine Phosphorous critical level and phosphorous requirement factor for wheat in Shashemene district.
- b) To determine economically optimum level; of nitrogen fertilizer for wheat production in the study area

## 2. MATERIAL AND METHODS

### 2.1. Site description

The project was conducted in, Shashemene districts of West Arsi Zone, Ethiopia. Shashemene districts are located at 38° 56' N, 7° 23' E, and average altitude of 2002 m.a.s.l. The rainfall pattern of the district is characterized by bimodal distribution with small rainy season *belg* (March-June) and main rainy seasons *Meher* (July-November). The annual total rainfall is 1520 mm mean annual average temperature of 19.7.

As far as soil type is concerned, the dominant soil unit of Shashemene district is andosol. Texturally, the soils of the area are classified as sandy loam. Wheat, Barley, potato, maize and teff are the major crops produced in this district.



**Map1: Location of Shashemene district in West Arsi Zone, Oromia**

### 2.2 Site selection

Potentially wheat growing areas in the district was selected with the collaboration of office of agriculture and natural resources of Shashemene district. Composite soil samples were collected from the selected area to analyze total soil pH, Nitrogen and phosphorous. Based on the result of analysis, the sites were classified in to low; medium and high level of available phosphorous.

### 2.3 Treatments and Experimental design

The study was conducted at three purposively selected areas or PA depending on their potential for wheat

production. In the first year, the study was conducted at six farmers' field to determine economically optimum level of Nitrogen in the district. Accordingly, four level of N (0, 46,69 and 92 kg ha<sup>-1</sup>) and four level of P (0, 20, 30, and 40 Kg ha<sup>-1</sup>) were factorial combined having three replications. In the second year, a basal dressing of nitrogen was given to all plots.

The P-calibration experiment was conducted at ten and eleven farmers' field in the second and third years respectively. Experimental plot size was 3m\*3m for each treatment. Treatments were five levels of P (0, 10, 20, 30 and 40 and Kg ha<sup>-1</sup>) and optimum amount of N-fertilizer applied uniformly for all plots.

The experiment was laid out in randomized complete block design (RCBD) with three replications. Representative composite soil samples were collected from each farmer's field before planting to the depth of 0-20cm for physio-chemical analysis. The recently introduced improved wheat variety (Ogolcho) was used for the trial. After 21 days of planting, intensive composite soil samples were collected from each plot to analyze the available phosphorous.

**Table 1: Treatment Combinations for determination of optimum Nitrogen**

Treatments (N,P) levels				
(0,0)	(0,10)	(0,20)	(0,30)	(0,40)
(46,0)	(46,10)	(46,20)	(46,30)	(46,40)
(69,0)	(69,10)	(69,20)	(69,30)	(69,40)
(92,0)	(92,10)	(92,20)	(92,30)	(92,40)

**Table 2: Treatments for determination of P-critical and P-requirement factor**

Treatments	Optimum N (kg/ha)	Level P kg/ha	Source of fertilizer
T1	46	0	UREA
T2	46	10	UREA and TSP
T3	46	20	UREA and TSP
T4	46	30	UREA and TSP
T5	46	40	UREA and TSP

## 2.4 Data collection

Physiochemical properties, such as pH, available phosphorous, EC, Total nitrogen and soil texture were analyzed. In addition, yield data was collected and recorded.

## 2.5 Soil sample collection and analysis

Composite soil samples for laboratory chemical and physical characterization was collected at 0-20cm depth from each field initially before fertilizer application. Composite samples were also collected three weeks after planting for the determination of available phosphorus and analyzed using Olsen method.

## 2.6 Determination of critical P concentration

Critical value for soil Phosphorus was determined from the relationship between relative yields (yield /maximum yieldx100) and P-soil test values. Critical value is the value below which there is P response and above which there is no P –response. Critical P value was determined following the Cate-Nelson graphical method where soil P values (available p after 3 weeks of application extracted using Olsen method) were put on the X-axis and the relative yield values on the Y-axis. The Cate-Nelson graphical method is based on dividing the Y-X scatter diagram into four quadrants and maximizing the number of points in the positive quadrants while minimizing the number of points in the negative quadrants (Nelson and Anderson, 1977). Percentage yield values were obtained for a wide range of locations where results of fertilizer rate studies are available.

$$\text{Relative yield\%} = \frac{\text{Yield}}{\text{MaximumYield}} * 100$$

## 2.7 Determination of P requirement factor

Phosphorus requirement factor is the amount of P in kg needed to raise the soil P by 1ppm. Phosphorus requirement enables to determine the quantity of P required per hectare to raise the soil test by 1ppm, and to determine the amount of fertilizer required per hectare to bring the level of available P above the critical level.

$$\text{Phosphorus requirement factor} = \frac{\text{kg P applied}}{\Delta \text{ soil P}}$$

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

## 2.8 Data management and Analysis

All agronomic and soil data which will be collected across locations will be properly managed using the EXCEL computer software. The collected data was subjected to the analysis of variance using the SAS/STAT computer package version 9.0 (SAS Institute, 2001). Statistical (Minitab-19) was used to develop graphs and correlation analysis

## 2.9 Economic Analysis

Economic analysis was performed to investigate the economic feasibility of the treatments. Partial budget and MRR (%) analyses were used to determine the economic analysis (CIMMT, 1988). The average open market price (Birr kg<sup>-1</sup>) for different crops and the official prices of N, P and K fertilizers were used for analysis. Marginal rate of return (MRR) was calculated using the formula given blow.

$$\text{MRR} = \frac{\text{Net Income From Fertilized Field} - \text{Net Income From Unfertilized Field}}{\text{Total Variable Cost From Fertilizer Application}}$$

**Total variable cost** is a cost incurred due to application of P fertilizer (both but in separate of Soil test based P calibration result and farmers' fertilizer rate) with the assumption that the rest of the costs incurred are the same for all treatments.

**Gross income** is obtained by multiplying mean grain yield (kg/ha) of each treatment by the price of one kg of the grain. **Net income** is calculated by subtracting the total variable cost from the gross income.

## 3. Result and Discussion

### 3.1 Soil physiochemical characteristics of the study sites

Composite soil samples were collected from each experimental site to characterize the physiochemical properties. The following (table1) showed the soil laboratory analysis to determine the physical and chemical properties of the sites before planting. Soil PH. Soil organic carbon, electrical conductivity (EC), total nitrogen (TN), initial soil phosphorous (pi) and soil texture were analysed.

**3.1.1 Soil pH:** soil pH is an indicator of soil acidity or alkalinity level. Accordingly, the average pH levels of the study sites were 6.71 which is in the acceptable range for optimum crop production (table1). The level pH usually affects the availability of major crop nutrients. The desirable soil pH range for optimum plant growth varies among crops. Generally, soil pH 6.0-7.5 is recommended for most plants as most nutrients become available in this pH range (US Environmental Protection Agency, 2004).

**Table1: Soil physiochemical properties of experimental sites before application**

Sites	Soil properties							
	Soil pH	Initial in ppm	Ava.P	SOC (%)	Total N (%)	EC mmhoms/cm	C:N	Soil texture
1.	6.50	7.72		3.66	0.14	0.19	26.14	Sandy Loam
2.	5.98	10.00		2.83	0.17	0.57	16.65	Sandy Loam
3.	6.50	7.40		2.66	0.15	0.18	17.73	Sandy Loam
4.	7.20	31.00		2.37	0.14	0.13	16.93	Sandy Loam
5.	6.75	13.18		2.82	0.17	0.23	16.59	Sandy Loam
6.	7.35	18.82		2.96	0.18	0.19	16.44	Sandy Loam
7.	7.12	20.76		2.83	0.15	0.20	18.87	Sandy Loam
8.	6.50	11.20		2.66	0.22	0.21	12.09	Sandy Loam
9.	6.50	15.04		2.83	0.14	0.19	20.21	Sandy Loam
10.	5.98	14.12		2.98	0.17	0.57	17.53	Sandy Loam
11.	6.50	19.96		2.68	0.15	0.18	17.87	Sandy Loam
12.	7.20	12.28		2.37	0.14	0.13	16.93	Sandy Loam
13.	6.75	13.32		2.82	0.17	0.23	16.59	Sandy Loam
14.	7.35	18.88		2.96	0.18	0.19	16.44	Sandy Loam
15.	7.12	20.24		2.83	0.15	0.20	18.87	Sandy Loam
16.	6.50	17.84		3.16	0.22	0.21	14.36	Sandy Loam
17.	6.78	14.22		3.71	0.25	0.23	14.84	Sandy Loam
18.	6.40	10.56		3.66	0.22	0.21	16.64	Sandy Loam
19.	6.90	15.04		2.99	0.18	0.19	16.61	Sandy Loam
20.	6.50	7.72		2.79	0.14	0.19	19.93	Sandy Loam
<b>Mean</b>	<b>6.71</b>	<b>14.96</b>		<b>2.92</b>	<b>0.17</b>	<b>0.23</b>	<b>17.41</b>	

**3.1.2 Soil Organic carbon:** Soil organic carbon is a measurable component of soil organic matter. It is an indicator of the potential of soil nutrient retention and turnover, soil structure, moisture retention and carbon sequestration. As it is indicated in table 1, the average SOC of the study site was 2.92%. The study by Emanuel *et.al*, 2018 also showed that soil organic carbon on agricultural land varies from 1.34-9.75% depending on its degree of degradation and land management.

**3.1.3 Total Nitrogen:** Total Nitrogen (Tot N) exists in organic forms and inorganic (or mineral) forms such as plant available ammonium (NH<sub>4</sub><sup>+</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>). It was identified that soil total nitrogen content of the study area was 0.17% which is found to be classified as low (table1). The majority of Tot N is bound in soil organic matter. Soil microorganisms decompose organic matter to liberate energy stored in chemical bonds to fuel their activity and to harvest carbon and nitrogen to build their biomass. Soil biota requires nitrogen for the synthesis of their proteins and other nitrogen containing organic molecules. As dynamic microbial populations grow, if there is insufficient nitrogen in the organic matter they are decomposing they can out-compete crop plants for inorganic nitrogen. This is called immobilization. Conversely, if the organic matter contains sufficient nitrogen to satisfy microbial demands, excess inorganic N is released to crop plants (Harold van, *et.al*, 2020)

**3.1.4 Soil available phosphorous**

Next to nitrogen, phosphorus is often the limiting nutrient for crop production in tropical soils. In soil phosphorus availability studies, the selection of an appropriate methodology is a key factor. In Ethiopia, the Olsen's NaHCO<sub>3</sub> method (Olsen et al., 1954) is often used for determining soil available P. Available P contents of most of tropical soils were categorized as very low for available is p<5 mg kg<sup>-1</sup>, low for available p is between 5–9 mg kg<sup>-1</sup>, Midium for available p between 9-17 mg kg<sup>-1</sup> and high for available p between 18–25 mg kg<sup>-1</sup> (Cottenie, 1980, *FAO Soil Bulletin* 38/2, 2012). The average available phosphorous content of the soil in the study area before the application of the treatment were 14.96ppm (Table1). Accordingly, P contents of the soil in the study area were categorized under medium status. Application of phosphorous fertilizer at different rate significantly affect soil available phosphorous (p<0.05). Soil available p was increasing with increased level of application. Available P (Olsen extractable) in the studied sites varied between 18.64 and 32.04 mg kg<sup>-1</sup> after 21 days of the treatment application (Table2). Therefore, according to Cottenie, 1980, *and FAO Soil Bulletin* 38/2, 2012, available p of the site after application of phosphorous fertilizer was increased and categorized to be very high.

This result is also in agreement with the findings of Debele, 2001, Mamo et al. 2004, Negassa and Gebrekidan, 2010 who reported that availability phosphorous to the crop usually affected by the level of soil phosphorous fertilizer applied, soil organic matter content and level of soil pH. They argued that Soils with inherent pH values between 6 and 7.5 are ideal for P-availability, while pH values below 5.5 and between 7.5 and 8.5 limits P-availability to plants due to fixation by aluminum, iron, or calcium. Soil PH of the study area was 6.71 (Table 1) which is nearly neutral and ideal level for availability of phosphorous to the crop.

**Table2: Available Phosphorous after 21 days of application**

Treatment	Level of P in ppm/ha applied	Average Available P in PPM	Std dev	Minimum	Maximum
1	0	14.07 <sup>d</sup>	4.92	5.50	28.42
2	23	18.64 <sup>c</sup>	4.32	10.00	30.68
3	46	27.17 <sup>b</sup>	5.25	18.33	37.00
4	69	29.77 <sup>ab</sup>	6.92	17.00	41.00
5	92	32.04 <sup>a</sup>	6.25	19.00	47.00
CV (%)		15.44			
LSD(0.05)		2.86			

**3.2 Economically optimum level of Nitrogen fertilizer**

The maximum grain yield (5358kg/ha) was obtained at the combined application of 46kg/ha N and 92kg/ha P<sub>2</sub>O<sub>5</sub> while the lowest grain yield (1873kg/ha) was obtained at the control treatment. Similar study by Shaver (2014) indicated that 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. The main effect for nitrogen fertilizer significantly (p<0.05) affected the grain yield. It was significantly vary from 2428kg/ha to 4587kg/ha in applying 46kg N and 92kgN respectively (Table3)

However, there is no significance differences (p<0.05) between the combined effects of Nitrogen and phosphorous fertilizers level above 46kg/ha on grain yield response. This implies that application of N and P<sub>2</sub>O<sub>5</sub> greater than 46kg/ha may not be economically important. On the other hand, the partial economic analysis was conducted to determine economically optimum level of nitrogen fertilizer. Accordingly, maximum net benefit of 114425.00 birr was obtained where 69kg/ha N was applied. For a treatment to be considered as worthwhile to



farmers, 100% marginal rate of return (MRR) was the minimum acceptable rate of return Dejene *et al*, 2020. Therefore, 46 N kg ha<sup>-1</sup> N fertilizers was determined as economically feasible optimum N rates at 2655%, MRR on Eutric andosol in Shashemene district for Bread wheat.

**Table2: Partial budget analysis using CIMMT, 1988**

No .	N-levels	UREA in kg	Unit price	TVC	Grain YLD	Unit price	Gross Benefit	Net Benefit	MRR (%)
1	0	0	15	0	2297.00	25	57425	57425	0
2	46	100	15	1500	3950.00	25	98750	97250	2655
3	69	150	15	2250	4667.00	25	116675	114425	2200
4	92	200	15	3000	4509.00	25	112725	109725	2076

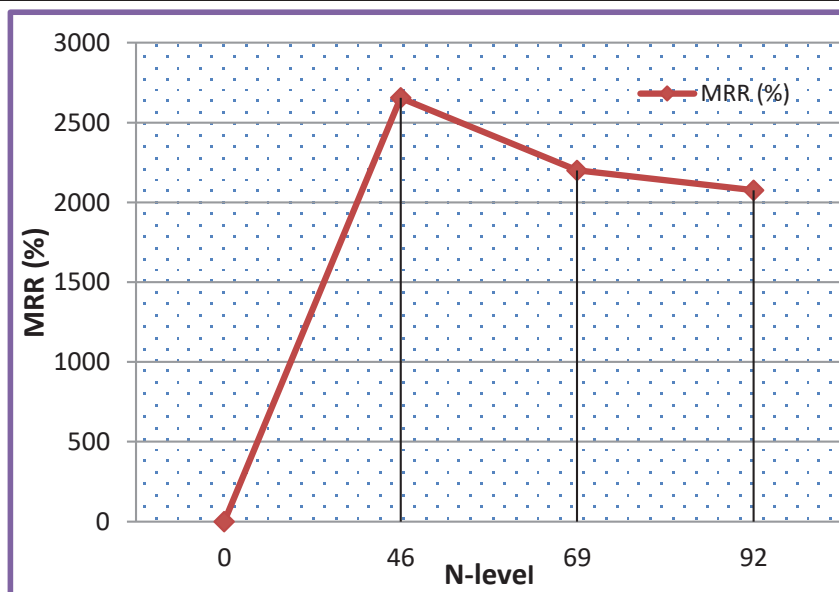


Figure1: The maximum MRR with the optimum N-applied

Table 3: Response of wheat grain yield to NP fertilizers application

Level of N in kg/ha	Level of phosphorous(P <sub>2</sub> O <sub>5</sub> ) in kg/ha			
	0	23	46	92
0	1873 <sup>e</sup>	2154 <sup>fg</sup>	2308 <sup>fg</sup>	2853 <sup>defg</sup>
46	2428 <sup>efg</sup>	3516 <sup>cdef</sup>	4498 <sup>abc</sup>	5358 <sup>a</sup>
69	3886 <sup>bcde</sup>	4093 <sup>abcd</sup>	4600 <sup>abc</sup>	4891 <sup>abc</sup>
92	4587 <sup>abc</sup>	5106 <sup>ab</sup>	5319 <sup>a</sup>	4626 <sup>abc</sup>
LSD (5%)	1466			
CV	12.47			

### 3.3 Determination of Phosphorus Critical Value

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 as 'critical soil test p levels.

The critical P concentration (P<sub>c</sub>) was determined from the scatter diagram drawn using relative grain yields of bread wheat and the subsequent soil test P values. According to the Nelson, p critical level will be determined for the top 20 cm of soil using Olsen method. The P critical defined by the Cate Nelson method in this study area was about 21 mg P kg<sup>-1</sup>, with mean relative yield response of about 75% (Figure2). The relative crop yield showed a decreasing trend even though the soil test P value is above the critical. If available P is increasing beyond this level, the cost of additional P fertilizer to produce extra yield would likely be greater than the value of the additional yield (Kefyalew A. et al, 2017). These results are in general in accordance with the results of several studies, which showed the positive response of wheat grain yield and other cereals to phosphorous fertilization in Ethiopian highland areas (Admassu, 2017; Agegnehu et al., 2015). Additionally, Admassu (2017)

also stated the importance of soil test based P fertilizer application for improving yield and yield components of tef and wheat in Ethiopian.

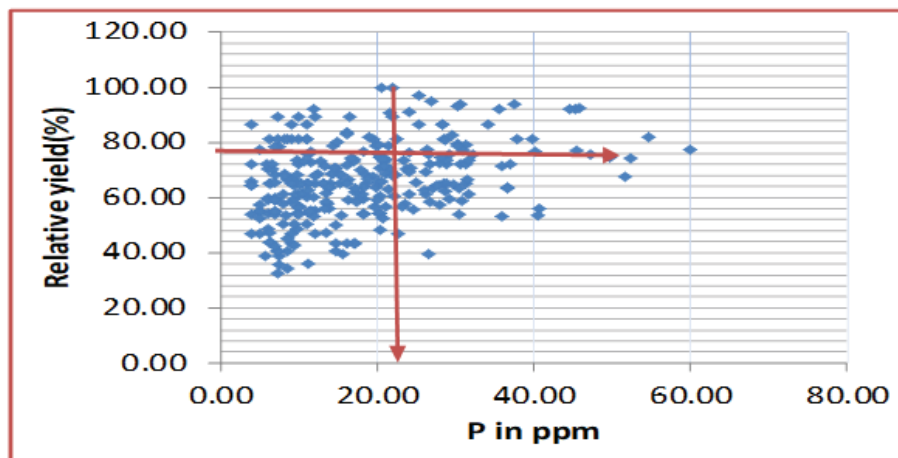


Figure 2: Phosphorus Critical Value as determined by Olsen method

### 3.4 Phosphorous requirement factor

Calculated phosphorus requirement factor (Pf) for bread wheat production on Eutric andosol in Shashemene district was 4.43 (Table4). Phosphorous requirement factor (Pf) is 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 (pf).

**Table4: Phosphorous requirement factor for wheat in Shashemene district**

No.	Phosphorous (P) fertilizer applied (kg P/ha)	Average soil P(ppm)	P- increase over control ( $\Delta$ soil P)	P- requirement factor (Pr)
1	0	18.20	-	-
2	10	21.10	2.9	3.44
3	20	23.15	4.95	4.04
4	30	24.25	6.02	4.98
5	40	25.75	7.55	5.29
<b>Average</b>				<b>4.43</b>

### Conclusion and Recommendations

Chemical fertilizers are one of the most important inputs for maintaining agricultural production and productivity of the country. Adequate and balanced levels of phosphorus (p) and other nutrient are important to get maximum and sustainable production. Therefore, sound soil test calibration is essential for successful fertilizer program and crop production. Phosphorus calibration study has been conducted on bread wheat for two years (2019-2020 growing season) at Shashemene district.

Accordingly, economically optimum nitrogen rate (46 kg N/ha), critical P (Pc) concentrations (21 ppm) and P (Pf) requirement factors (4.43) for bread wheat was determined for the study area. Farther verification of the result on farmers' field could be a prerequisite before disseminating the technology to the user.

### Acknowledgements

First of all, I would like thank God who enables me to get success in every steps of the research activity. Secondly, the authors would like to thank Oromia Agricultural Research Institute for financial support and Adami Tulu Agricultural Research Center for providing all the necessary facilities required for the research. At last but not at least, our special thank also forwarded to all staff members, especially to the technical assistances: Abdo Oshe, Gebremikael Adera, Qasim Barissa and Jemal Qure for their unreserved effort from land preparation to harvesting and data collections

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