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*Research Article*

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# Soil Test-Based Crop Response Phosphorus Calibration Study on Bread Wheat (*Triticum Aestivum L*) in Liban Chukala District, East Shewa Zone, Oromia, Ethiopia

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**ABSTRACT**
Nutrient mining due to sub-optimal fertilizer use on one hand and unbalanced fertilizer use on the other have favored the emergence of multi-nutrient deficiency in Ethiopian soils. Therefore, the study was conducted on twenty-one farmers' fields in the Liban Chukala District of East Shewa Zone of Oromia, during the main cropping seasons of 2019-2022. The study aimed to determine the economically optimum rate of nitrogen fertilizer in the first year. However, in the second two consecutive years the experiment was conducted to determine phosphorus critical (Pc) and phosphorus requirement factor (Pf and the treatments consisted of six levels of phosphorus (0, 10, 20, 30, 40, and 50) kg $ha^{-1}$ combined with a single level of nitrogen (69 kg $ha^{1}$) that gave a total of seven treatments. The experiments were laid out in randomized complete block design (RCBD) with two replications and the gross plot, size was 4 m x 5 m (20 $m^2$) was used to determine phosphorus critical (Pc) and also harvested from 4$m^2$ plot areas. The analysis of variance indicated that, thousand kernels weight, and harvest index were not significantly ($p<0.05$) influenced by applied NP fertilizers. On the other hand, the analysis of variance indicated that Plant height, spike length, number of seeds per spike, biomass yield, and grain yield were highly significantly ($p <0.01$) influenced by soil test-based phosphorus fertilizer application. The result indicated that the highest (87.82 cm) plant height, the highest (1013 kg $ha^{-1}$) biomass, and the highest (4517 kg $ha^{-1}$) grain yield were recorded by 40 kg P $ha^{-1}$. Moreover, 23ppm phosphorus critical (Pc) and 9.86ppm phosphorus requirement factor (Pf) were identified for bread wheat production for the farmers of Liban Chukala District.

**Keywords:** Applied Phosphorus, Bread Wheat, Cate and Nelson Graph, NPS, Nitrogen, Phosphorous Critical (PC), Phosphorus Requirement Factor (PF), Soil and Yield

## Introduction

Wheat is a type of cereal crop cultivated for its grain and used worldwide as a staple food. The many species of wheat together make up the genus Triticum; the most widely grown is common wheat (Triticum aestivum). Ethiopia is also one of the largest wheat producers in Sub-Saharan Africa and approximately 80% of the wheat area is planted to bread wheat. In Ethiopia wheat is mainly grown in the highlands, which lie between 6 and 16° N latitude and 35 and 42° E longitude, at altitudes ranging from 1500 to 2800 m above sea level and mean minimum temperatures of 6°C to 11°C. In Arsi, Bale, and Shewa Zones, the soil, moisture, and disease conditions within the range of 1900-2300m altitude zone are favorable for the production of early and intermediate maturing varieties of bread wheat. This is estimated to comprise 25% of the total wheat production area, while the remaining 75% falls in the 23002700 m altitude zone.

Ethiopia is not self-sufficient in wheat and a substantial gap primarily due to inefficient transfer of technology and the lack of necessary inputs and blanket-type fertilizer application which is based on soil color characteristics rather than on soil test results and crop requirements. According to the report of the Food and Agriculture Organization of the United Nations world's total wheat production in 2019 was estimated at 765 million tons from a total of 215 million hectares area harvested; with an average yield of 3547 kg $ha^{-1}$. However, in Ethiopia, wheat production

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in 2019 was estimated at 5.3 million tons from a 1.7 million ha area harvested with an average yield of 2970 kg ha-1. According to this report despite the large area of wheat in Ethiopia, the average yield of wheat is 19.4 % far below the world's average yield.

Each type of plant is unique and has an optimum nutrient range as well as a minimum required level. Below this minimum level, plants start to show nutrient deficiency symptoms. Excessive nutrient uptake can also cause poor growth because of toxicity. Therefore, the proper amount of application and the placement of nutrients is important. Moreover, Sonon and Zhang reported that soil test calibration is specific for each crop type and they may also differ by soil type, climate, and crop variety and relates soil test measurement in terms of crop response and essential that the results of soil tests be calibrated against crop responses from applications of the plant nutrients in question as it is the ultimate measure of a fertilization program. So, to tackle these problems site-specific and crop-specific new fertilizers recommendation such as NPS (19% N, 38% $P_2O_5$, and 7% S) have been evaluated by the researchers in Ethiopia as a means of supplementing nutrient depletion from soil and then for successful crop production. Therefore, this study was undertaken with the following objectives:

- To determine the economically optimum N fertilizer for bread wheat in the Liban Chukala district.
- To determine Phosphorus critical and phosphorus requirement factors for bread wheat.

## Materials and Methods

### Description of the Experimental Site

The experiment was conducted on a Farmers' field in Liban Chukala district, east Shewa Zone of Oromia regional state in central Ethiopia for three consecutive years (2018 -2022). Liben is one of the woredas in the Oromia Region of Ethiopia. It is part of the East Shewa Zone located in the Great Rift Valley. Mount Zuqualla (2989 m) is also a prominent peak as well as a notable landmark, as the monastery of Saint Gebre Manfas Qeddus is located on it.

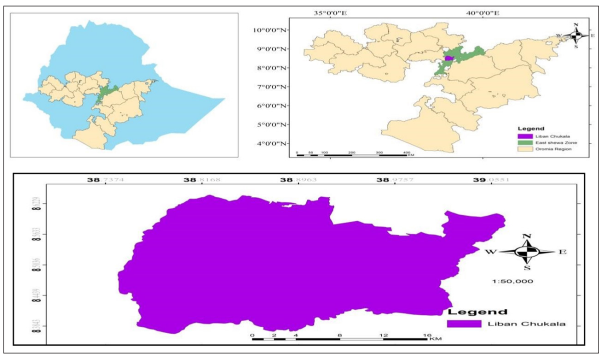


**Figure 1:** Location Map of Liban Chukala District

### Experimental Materials

- Bread wheat variety (Qaqaba) was used for the study area.
- TSP (46% $P_2O_5$),
- NPS (19%N: 38%$P_2O_5$:7%S) and Urea (46% N) were used

### Treatments and Experimental Design

In the first year, the experiment was conducted to determine the optimum nitrogen rate and the treatments consisted of factorial combinations of three levels of NPS (0, 100, and 200) kg $ha^{-1}$ with six levels of nitrogen (0, 23, 46, 69 92 and 115) kg $ha^{-1}$ that gave a total of eighteen treatments. However, by using the determined optimum Nitrogen (69 kg $ha^{-1}$) in the first year; phosphorus critical (Pc) and phosphorus requirement factor (Pf) were determined in the second two consecutive years. So the treatments consisted of six levels of phosphorus (0, 10, 20, 30, 40, and 50) kg $ha^{-1}$ combined with a single level of nitrogen (69 kg $ha^{-1}$) that gave a total of seven treatments.

The experiments were laid out in randomized complete block design (RCBD) with two replications and the gross plot size was 4 m x 5 m (20 $m^2$) were used and also harvested from 4$m^2$ plot areas.

### Management of the Experiment

The experimental fields were prepared following the conventional tillage practice which includes three times plowing before sowing the crop. As per the specification of the design, a field layout was prepared; the land was leveled and made suitable for crop establishment. Sowing was done in mid-July of 2018, 2019, and 2020 using a seed rate of 150 kg $ha^{-1}$. A full dose of NPS and TSP as per the treatment and one-third of N alone was applied at sowing time. The remaining two-thirds of N alone was top-dressed at the mid-tillering crop stage. While experimenting, other necessary agronomic management practices such as fungicide (Natura) sprayed for yellow rust and herbicide (Palas) sprayed to control both grass leaf and broad leaf were carried out uniformly for all treatments.

### Data Collection and Measurement

### Yield Components and Yield Parameters

**Plant Height (cm)** Plant height was measured from the soil surface to the tip of a spike (awns excluded) from 10 randomly tagged plants from the net plot area at physiological maturity

**The Number of Seeds Per Spike** The mean number of seeds per spike was recorded as an average of 10 randomly taken spikes from the net plot area.

**Thousand Kernel Weight** Thousand kernels weight was determined based on the weight of 1000 kernels sampled from the grain yield of each net plot by counting using an electronic seed counter and weighed with electronic sensitive balance. Then the weight was adjusted to 12.5% moisture content.

**Spike Length (cm)** was measured from 10 randomly selected wheat heads per plot at harvesting time

**Aboveground Dry Biomass Yield** The aboveground dry biomass yield was determined from plants harvested from the net plot area after sun drying to a constant weight and expressed in kg $ha^{-1}$.

**Grain Yield** The grain yield was taken by harvesting and threshing the grain yield from the net plot area. The yield was adjusted to 12.5% moisture content and expressed as yield in kg $ha^{-1}$.

**Harvest Index (HI)** The harvest index was calculated as the ratio of grain yield per plot to total above-ground dry biomass yield per plot expressed as a percent.

**Soil Sample Collection and Analysis** After 21 days composite soil samples were collected from each plot by using a soil auger from a depth of 0-20cm and analyzed for phosphorus

**Determination of Critical P Concentrations**
Critical phosphorus concentration is below which there was a response while above phosphorus was not responded. Intensive composite soil samples were collected after 21 days of planting. At this time the applied phosphorus was ready to be utilized by the crop. Critical P value (mg/kg) has been determined following the Cate-Nelson graphical method where soil P values were put on the X-axis and the relative grain yield values on the Y-axis

$$\text{Relative grain Yield \%} = \frac{\text{Yield *100}}{\text{Maximum Yield}}$$

The Cate-Nelson graphical method was dividing the Y-axis and X-axis 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.

**Determination of Phosphorus Requirement Factor**
The phosphorus requirement factor (Pf) is the amount of Phosphorus in kg needed to raise the soil P by 1ppm. The average of Olsen P-ppm after 21 days of each applied P-treatment and Phosphorus increase over the control were calculated. Finally, Pf (phosphorus requirement factor) was determined by the following formula.

$$\text{Pf} = \frac{\text{Kg P applied}}{\Delta \text{ Soil P}|}$$

**Statistical Analysis**
The data were subjected to analysis of variance (ANOVA) as per the experimental design using GenStat (15$^{th}$ edition) software [1]. The Least Significance Difference (LSD) at a 5% level of probability was used to determine differences between treatment means.

**Results and Discussion**
**Determination of Phosphorus Critical Concentration and P-Requirement Factor**
The Cate_Nelson graphical method was employed to determine the phosphorus critical point for bread wheat in the Dugda district. Accordingly, the phosphorus critical concentration above which the responses of the crop become minimal was 23 ppm for bread wheat production (Figure 1). The phosphorus requirement factor is the amount of p in kg needed to raise the soil p by 1 ppm. Moreover, the determination of Pc defined by the Cate Nelson method for the study area was 23 ppm. The soil available phosphorus vs. phosphorus fertilizer of the district ranges from 13.96 and 25.48 ppm for 0 and 50 kg P ha$^{-1}$ respectively. The P requirement factor (Pf), is computed from the difference between available soil test P values from plots that received 0-50 kg P ha$^{-1}$. Where the available p vs. p fertilizer applied ranges from 13.96 to 25.48 ppm for 0 and 50 kg P ha$^{-1}$ respectively. Where the Pf of the district ranged from 2.29 to 14.13 and the overall average Pf of all treatments was 9.86 for the study area.

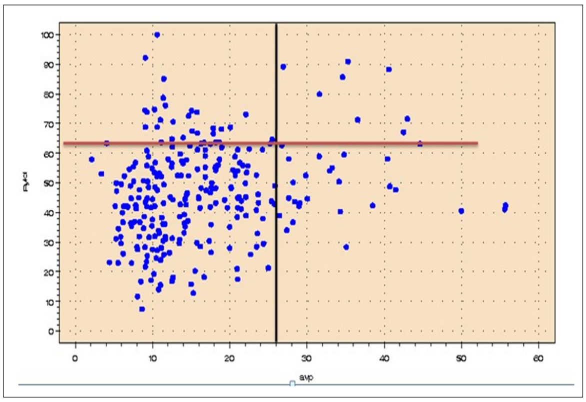

**Figure 2:** Graph of phosphorus critical for bread wheat production at Liban Chukala district

**Table 1: Phosphorus Requirement Factor of Bread Wheat in Liban District**

| -1kg P ha | Olsen - P (ppm) | | P increase Over control | -1 *Pf kg P | (ppm)/ Δ P |
|---|---|---|---|---|---|
| | Range | Average | | | |
| 0 | 5.36-21.32 | 13.96 | 0 | 0 | |
| 12.59 | 5.25-27.64 | 18.85 | 4.37 | 0 | |
| 16.96 | 5.6-40.42 | 20.13 | 11.41 | 2.29 | |
| 24 | 4.08-24.28 | 16.61 | 1.59 | 1.75 | |
| 14.18 | 5.32-25.52 | 17.9 | 2.83 | 18.87 | |
| 15.42 | 3.4-26.32 | 25.48 | 2.26 | 14.13 | |
| **Mean** | | **14.85** | | **9.86** | |

**Thousand Kernels Weight and Harvest Index as Influenced by Phosphorus Fertilizer**
The analysis of variance indicated that a Thousand kernel's weight and Harvest index were not significantly (p<0.05) affected by the main effect of phosphorus fertilizer application rates during the years of calibration study (Table 1).

**Table 2: Effect of NP fertilizer on TKW and harvest index of bread wheat**

| Treatment | | TKW (g) | HI (%) |
|---|---|---|---|
| -1 | -1 | | |
| P (kg ha ) | N (kg ha ) | | |
| 0 | 0 | 67.31 | 41.96 |
| 0 | 69 | 68.66 | 44.14 |
| 10 | 69 | 67.77 | 44.27 |
| 20 | 69 | 66.88 | 43.03 |
| 30 | 69 | 67.21 | 43.33 |
| 40 | 69 | 67.69 | 42.16 |
| 50 | 69 | 67.39 | 42.20 |
| LSD (0.05) | | NS | NS |
| CV (%) | | 0.9 | 1.8 |
| P - values | | 0.245 | 0.103 |

**Spike Length**
The analysis of variance indicated that spike length was highly significantly (p<0.01) affected by the main effect of phosphorus fertilizer application rates during the years of calibration study (Table 2). The highest (7.385 cm) and lowest (6.81 cm) spike

lengths were recorded at the maximum application of (50 kg P ha$^{-1}$) and control plots respectively. The result is concurrent with the findings of who recorded the highest 6.7 cm spike length by application of 44 P kg ha$^{-1}$ [2].

**Plant Height**

The analysis of variance indicated that plant height was highly significantly ($p<0.01$) affected by the main effect of phosphorus fertilizer application rates during the years of calibration study (Table 2). The highest (87.82 cm) and the lowest (73.22cm) plant heights were recorded by application of (40 kg P ha$^{-1}$) and control plots respectively. This result is in line with the finding of who reported the highest (74.56 cm) plant height by application of 69 kg $P_2O_5$ ha$^{-1}$ for bread wheat [3].

**Number of Seeds Per Spike**

The analysis of variance indicated that the number of seeds per spike was significantly ($p<0.05$) affected by the main effect of phosphorus fertilizer application rates during the years of calibration study (Table 2). The highest (44.12 gm) and the lowest (38.72 gm) number of seeds per spike were recorded by application of (40 kg P ha$^{-1}$) and control plots respectively. The result is consistent with the report of Alemu, 2019) who reported the highest (47) number of seeds per spike by application of 69 $P_2O_5$ ha$^{-1}$ phosphorus fertilizer for bread wheat production.

**Biomass Yield**

The analysis of variance indicated that biomass yield was highly significantly ($p < 0.01$) affected by the main effect of phosphorus fertilizer application rates during the years of calibration study (Table 2). The highest (10.705 ton ha$^{-1}$) and the lowest (7.365 ton ha$^{-1}$) biomass yields were recorded by application of (40 kg P ha$^{-1}$) and control plots respectively. The result is in agreement with the report of who reported the highest (9.270 ton ha$^{-1}$) by application of 23 kg $p_2o_5$ ha$^{-1}$ for bread wheat production at the Weleh site [4].

**Grain Yield**

The analysis of variance indicated that plant height was highly significantly ($p<0.01$) affected by the main effect of phosphorus fertilizer application rates during the years of calibration study (Table 2). The highest (4517 kg ha$^{-1}$) and the lowest (3092 kg ha$^{-1}$) grain yields were recorded by application of (40 kg P ha$^{-1}$) and control plots respectively. The result is in line with the finding of who reported the highest (4281.3 kg ha$^{-1}$) grain yield by combined application of 69/92 kg ha$^{-1}$ nitrogen and phosphorus fertilizer respectively [5-21].

**Table 3: Effect of NP fertilizer on yield and yield components of bread wheat**

| Treatment | | Yield (kg ha-1) | SPL (cm) | PH (cm) | Bm(ton ha-1) | NSPS |
|---|---|---|---|---|---|---|
| P (kg ha$^{-1}$) | N (kg ha$^{-1}$) | | | | | |
| 0 | 0 | $3092^{c}$ | $6.810^{d}$ | $73.22^{e}$ | $7.365^{d}$ | $38.72^{c}$ |
| 0 | 69 | $4095^{b}$ | $7.210^{c}$ | $79.83^{d}$ | $9.275^{c}$ | $41.20^{b}$ |
| 10 | 69 | $4378^{ab}$ | $7.245^{bc}$ | $83.23^{c}$ | $9.875^{bc}$ | $43.09^{ab}$ |
| 20 | 69 | $4343^{ab}$ | $7.270^{abc}$ | $85.20^{bc}$ | $10.090^{ab}$ | $43.01^{ab}$ |
| 30 | 69 | $4473^{a}$ | $7.375^{ab}$ | $86.37^{ab}$ | $10.315^{ab}$ | $43.29^{ab}$ |
| 40 | 69 | $4517^{a}$ | $7.380^{a}$ | $87.82^{a}$ | $10.705^{a}$ | $44.12^{a}$ |
| 50 | 69 | $4277^{ab}$ | $7.385^{a}$ | $87.02^{ab}$ | $10.130^{ab}$ | $44.05^{a}$ |
| LSD (0.05) | | 288.0 | 0.1321 | 2.125 | 0.6413 | 2.528 |
| CV (%) | | 2.8 | 0.7 | 1.0 | 2.7 | 2.2 |
| P - values | | < .001 | < .001 | < .001 | < .001 | 0.010 |

**Conclusion and Recommendation**

The study revealed that applying 40 kg of phosphorus and 69 kg of nitrogen per hectare significantly boosted bread wheat yields in the Liban Chukala District, with the best results showing a grain yield of 4517 kg per hectare. The phosphorus critical concentration was identified as 23 ppm, and the phosphorus requirement factor was 9.86 ppm. Phosphorus fertilization improved plant traits like height, spike length, and overall yield, addressing soil nutrient depletion in the area. Based on these findings, farmers in the district are encouraged to use soil test-based fertilizer recommendations, applying 40 kg of phosphorus and 69 kg of nitrogen per hectare to get the most out of their wheat crops. Promoting this tailored approach to fertilization through agricultural extension services can help increase wheat productivity and contribute to food security in Ethiopia. Continued research will also be valuable in refining fertilizer use across different soil types and wheat varieties.

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