Asian Journal of Applied Science and Technology (AJAST)
Volume 10, Issue 1, Pages 192-200, January-March 2026

On farm Verification of Soil Test Crop Response Based Phosphorus Recommendation on Bread Wheat in Debre Libanos District of North Shewa Zone, Oromia, Ethiopia

Dejene Getahun[1*], Dereje Girma[2] & Meron Tolesa[3]

[1,2,3]*Oromia Agricultural Research Institute, Fitche Agricultural Research Center, Oromia, Ethiopia.*
Corresponding Author (Dejene Getahun) Email: dejenegetahun2009@gmail.com[*]

DOI: https://doi.org/10.38177/ajast/2026.10116

Article Received: 26 January 2026 | *Article Accepted: 27 March 2026* | *Article Published: 30 March 2026*

ABSTRACT

A negative nutrient balance results from nutrient removal, which is caused by agricultural practices that do not restore the nutrients that crops have taken out. Therefore, the study was conducted on nine farmers' fields in the Debre Libanos District of North Shewa Zone of Oromia during the main cropping seasons of 2024-2025. These studies were conducted to verify the feasibility of the PC and Prf, and to popularize and create awareness about the technology. The treatments consisted of blanket fertilizer recommendations, soil test crop response-based fertilizer recommendations, and control treatments. The experiments were laid out in a randomized complete block design (RCBD) and replicated across farmers' fields. The gross plot size was 10 m x 10 m (100 m²). The highest (88.38 cm) plant height, the highest (8.52 cm) spike length, the highest (10963 kg ha^{-1}) biomass, and the highest (4282 kg ha^{-1}) grain yield were recorded from STCRBFR treatments. The economic analysis revealed that for a treatment to be considered advisable to farmers (100% marginal rate of return), soil test crop response-based fertilizer recommendation is profitable, which gave the highest (306,880.07 Birr) net return with an acceptable (1355.86) marginal rate of return and was recommended for farmers in the Debre Libanos district. On the other hand, the analysis of variance indicated that plant height, spike length, biomass yield, and grain yield were highly significantly ($p < 0.05$) influenced by soil test crop response-based phosphorus fertilizer application. Moreover, 9.5 ppm phosphorus critical (Pc) and 14.23 phosphorus requirement factor (Prf) were verified and recommended for bread wheat production area for the farmers of Debre Libanos District.

Keywords: Available Phosphorus; Blanket Fertilizer Recommendations; Crop Response-based Fertilizer Recommendations; Fertilizer; Nutrients; Phosphorus Critical; Phosphorus Requirement Factor; Soil Samples; Soil Test; Thresholds.

1. Introduction

Ethiopia is the second largest wheat producer in Africa. Ethiopia is not self-sufficient in wheat and has a substantial gap primarily due to inefficient transfer of technology and the lack of necessary inputs and blanket type fertilizer application based on soil color characteristics rather than on soil test results and crop requirements [6]. Depleted soil nutrients and ineffective mineral fertilizer application are the primary causes of small agricultural systems' low yield [5]. Over-fertilization not only inhibits the improvement of crop yield and quality, it also results in serious issues, such as hardening and acidification of the soil, aggravation of crop pests, leaching loss of soil nutrients, and threats to groundwater safety [4]. However, while wheat production has been increasing steadily over the past decades, the demand for the crop has outstripped domestic supply, forcing the country to cover about 30 % of the deficit through commercial imports and food aid [18].

The establishment and maintenance of a suitable balance between supplying sufficient phosphorus inputs to sustain production and minimizing diffuse phosphorous transfer and its associated effects on environmental quality are the biggest challenges facing modern agriculture with regard to phosphorus nutrition [16]. Accordingly, soil test-based fertilizer doses, especially those of macronutrients, are accepted as being more rational, balanced, efficient, and profitable as compared to the blanket recommendation. However, blanket applications of 100 kg ha^{-1} DAP and 100 kg ha^{-1} Urea were used all over the country irrespective of the climate, soil type, crop species or variety, altitude, precipitation, water availability, and evapotranspiration. This costs the country a huge amount of money in hard currency every year and disrupts the balance between providing sufficient phosphorous and its associated impact on soil quality.

Setting thresholds for phosphorus management in the high- and low-intensity farming systems requires the determination of the appropriate amounts and forms of phosphorus inputs, as well as the continuous development of efficient phosphorus cycle strategies designed to maintain economically viable production levels with minimal phosphorus transfer [3].Amounts of phosphorus fertilizer vary significantly depending on crop and soil factors, as well as differences in fertilizer recommendation philosophies. In general, when soil test levels are high, fertilizer recommendation is seen as a safeguard, with the intention that the recommender wants to be sure that fertilizer is not becoming a limiting factor and that crop production is at an optimal level.

Therefore, phosphorus calibration is a way to establish a relationship between a given soil test value and the yield response from adding nutrients to the soil as fertilizer. It provides information on how much nutrient should be used at a given soil test value to enhance plant growth without undue waste and ensure the validity of current P recommendations [7;8] Soil testing is designed to help farmers predict the available nutrient status of their soils. Once present nutrient levels are determined, growers can use the data to best manage which nutrients to apply, determine application rate, and make decisions about the profitability of their farms [9]. However, local assessments for the critical soil P values and soil P demand factors are low even for the country's major crops [8].

Currently, soil fertility research improvement is agreed with respect to site specific fertilizer recommendation in the country. However, as in all other regions of the country, fertilizer recommendations in the Debre Libanos district are also not based on soil test results. The experiment that was conducted at Wachale for phosphorus fertilizer recommendation for bread wheat producing areas has already established the P-critical value (9.5 ppm), requirement factor of phosphorus (14.23), and recommended nitrogen (92 kg ha^{-1}). Using the above critical concentration and requirement factor, verification of the determined P-critical value, phosphorus requirement factor, and N-level was conducted for the Wachale district, and promising results were obtained. Thus, this finding can be useful for similar agro-ecologies.

Debre Libanos District is found near Wachale and has almost similar agro-ecologies. Therefore, extrapolating and verify the findings obtained at Wachale Districts for Debre Libanos districts were prerequisite before reaching the end users.

1.1. General objective

This experiment was necessary in order to be confident in our recommendations for these established values prior to deploying the technologies to the users. Therefore, this trial was initiated for the following Specific objectives: (1) To verify the feasibility of the *phosphorus critical (Pc) and phosphorus requirement factor* (Prf); (2) To popularize and create awareness about the technology for bread wheat producers of the districts.

2. Material and Methods

2.1. Experimental Site Description

The trial was conducted in Debre Libanos district of North Shewa Zone, Oromia. The district is located at 85 km north of the capital Addis Ababa. It is located Geographically, existed between 09^0 36’0”and 09^0 45’0’’ North and 038^0 45’00‘’ and $39^0$0’00” East with altitude ranging from 1500 to 2700 masl. Maximum and minimum annual temperature is 23^{0}c and 15^{0}C, respectively. Its main rainy season occurs between May and September and the dry season lasts from October to April. Vertisols are the major soil types of the district. The area is characterized by a mixed crop-livestock production system.

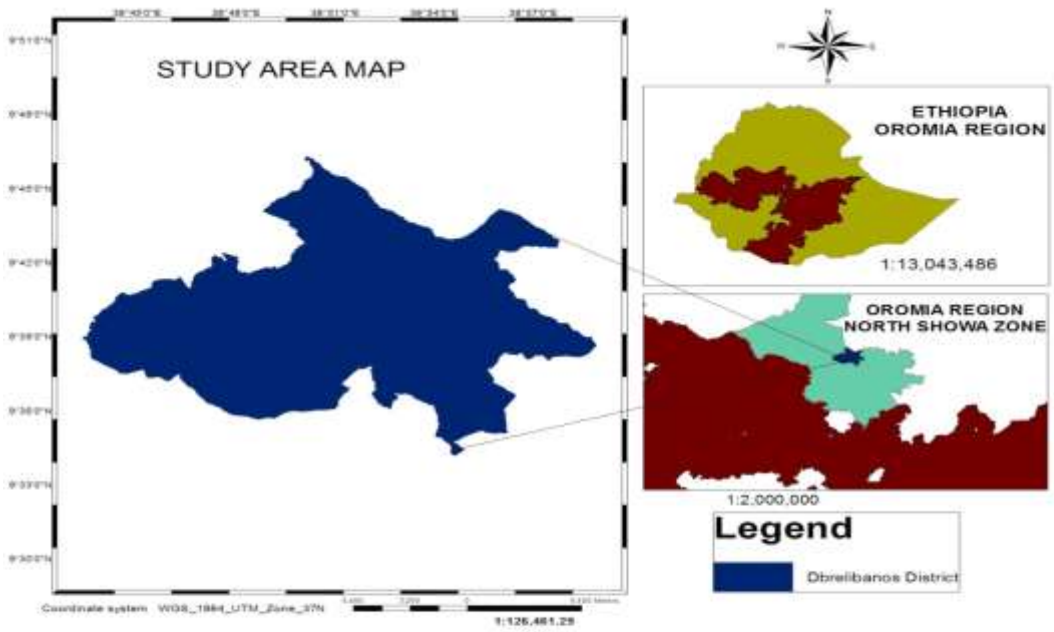

Figure 1. Map of the study area

2.2. Experimental design and Procedure

To select representative experimental fields, 20 composite soil samples were collected from different farmers' fields of the districts following the standard soil sampling procedures. Soil chemical analysis was done for available phosphorus, and then ten farmers' field with initial phosphorus concentration categories below critical p-concentration for the district selected.

The treatment considered were:

Treatments	Treatment combinations
Blanket type of fertilizer recommendation	DAP (46% of P_2O_5 and 18 % N) and Urea (46% N)/ha
Soil Test crop response-based P-recommendation	Soil test crop response-based p-recommendation plus Recommended N level (92 kg/ha)
Control	Without applying fertilizer

Then phosphorus fertilizer requirement was calculated from the formula: -

$$\text{Rate of P} - \text{ fertilizer to be applied} = [\text{PC} - \text{ Po}] * \text{ P requirement factor}$$

where Pc= (9.5 ppm), requirement factor of phosphorus (14.23), Po= Initial P values for site (mg/kg) and recommended N (92 kg/ha).

The experiment was laid out in Randomized complete block design (RCBD) with 10x10 (100 m^2) plot sizes. The farm field were prepared according to farmer's practice of the area. Regarding application of the fertilizers on the experimental plot, half of the Nitrogen (Urea fertilizer) was applied at planting time and the remaining was added after weeding. Whereas, phosphorus fertilizer was applied at sowing time in row methods. The indicator crop used in this study was bread wheat variety ‘Dambal’ with a seed rate of 150 kg/ha. All crop management practices including land preparation, planting, harvesting, protection against damage by disease and pests, weeding etc. were done uniformly for all treatments. Harvesting for grain yield determination were done from a net plot area of 1.5mx1.5m.

2.3. Soil Sampling and Analysis

About 30 composite Soil samples were collected from a depth of 0-20cm before planting from farm fields where experimental activities was conducted. The samples were air dried, ground using a pestle and mortar and allowed to pass through a 2 mm sieve. Following standard laboratory procedures, the samples were analyzed for specific physicochemical properties, predominantly soil pH, available P, total N and OM (Olsen et al., 1954).

2.4. Data Collected

Agronomic data related to the yield was gathered, and statistical analysis was performed on yield components like plant height, spike length, biomass yield, and grain yield.

2.5. Data Analysis

All data recorded and collected were subjected to the procedure of analysis of variance (ANOVA) using R-software program. The Economic practicability of the treatments was examined through economic analysis. Partial budget, dominance and marginal analyses were calculated. this was accomplished by using the average open market price of bread wheat (75 ETB kg^{-1}), Urea (N) and DAP (P) fertilizers. According to CIMMYT (1988), a treatment should be greater than the minimum considered acceptable to farmers (100%) and should be considered an acceptable choice for farmers of the study area. This enables to make farmer recommendations from marginal analysis. Marginal rate of return (MRR) for both farmer practice and soil test-based values were calculated as follows CIMMYT (1988),

$$\text{MRR} = \frac{\text{Net income from fertilized field} - \text{Net income from unfertilized field}}{\text{Total variable cost from fertilizer application}}$$

3. Result and Discussion

3.1. Soil Properties Before Sowing

Availability of phosphorous to the crop usually affected by the level of soil phosphorous fertilizer applied, soil organic matter content and level of soil pH. The result of the soil analysis revealed that soil pH of the study area was found between 5.39 and 5.72. According to [20], the soil pH of the study area was found in the range of moderately acidic rates. Whereas the phosphorus status of the study area was classified under low rates [13]. The low levels of available P found in the study areas' soil are consistent with findings from [2], who found that Ethiopian agricultural soils have low levels of available P because of crop harvest, soil erosion, and their naturally low P content. The organic matter (OC) and total nitrogen (TN) status in the study area varied from low to moderate and medium to very high, as indicated by [21] respectively.

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Table 1. Specific Soil physiochemical properties of experimental sites before application

Farmer fields	Soil pH	Available P (Olsen Method)	OC (%)	Total N
1	5.44	6.75	1.5	0.13
2	5.72	6.5	1.45	0.35
3	5.68	7.25	2.6	0.41
4	5.58	6.43	1.2	0.10
5	5.46	7.06	1.6	0.14
6	5.64	7.63	2.81	0.26
7	5.39	7.8	1.3	0.11
8	5.59	7.1	2.3	0.20
9	5.62	7.03	2.8	0.24
Average	5.57	7.06	1.95	0.22

3.2. The Responses of the Treatments on Yield and Yield Components of Bread Wheat

3.2.1. Plant height and spike length

From the analyzed data the plant height as well as spike length shows highly significant ($p<0.05$) among the treatments. The maximum plant height (88.38 cm) and spike length (8.52 cm) were obtained from STBFR (soil test-based fertilizer recommendation), and the minimum was gained from control (Table 2). In line with this finding, [1] found that plots treated with a crop response fertilizer treatment method based on soil tests had the highest- plants heights.

3.2.2. Biomass yield

Biomass yield was influenced by different treatments (Table 1). The highest biomass yield was obtained from soil test-based fertilizer recommendation rates (10963 kg/ha) and the minimum was from control treatments (3951kg/ha). The STBR were 7012kg/ha more than the control one in biomass yields. That is due to the soil test-based fertilizer application is appropriate in such a way that it receives an optimum fertilizer needed to feed the crop planted on the soil. The result is consistent with that of [21] who reported increased in biomass yield of bread wheat is may be due to application of balanced phosphorus and nitrogen fertilizers.

3.2.3. Grain Yield

There were significant differences ($P\leq0.05$) among the treatments in bread wheat grain yield. The maximum mean grain yield (4282kg ha^{-1}) was recorded from the application of STBCRPR, whereas the lowest (1512 kg ha^{-1}) was recorded from the control plot (table 2). STBCRPR gave (43.07 %) higher yield advantage than blanket (farmer's practices) fertilizers application. This result is in line with the finding of [1] who reported the highest grain yield from the plots treated with soil test-based crop response fertilizer application methods.

Table 2. Mean of plant height, Spike length, Biomass and grain Yield of bread wheat using different treatments

Treatment	Ph (cm)	SL (cm)	BM kg/ha	GY kg/ha
Control	63.51^{c}	5.367^{c}	3951^{c}	1512^{c}
Blanket fertilizer recommendation	83.24^{b}	7.764^{b}	7852^{b}	2993^{b}
STCRBFR	88.38^{a}	8.522^{a}	10963^{a}	4282^{a}
$LSD_{0.05}$	2.760	0.2368	793.25	430.06
CV (%)	3.5	3.3	10.5	14.7

3.2.4. Partial Budget Analysis

The first step in doing an economic analysis of on-farm experiments is to calculate the costs that vary for each treatment per hectare bases such as purchased inputs and labor. Farmers want to evaluate all the changes that are involved in adopting a new practice [14]. During this study, we were recording the costs payable for different purposes and the benefits produced due to the biomass and grain yields. Net return was calculated from the total revenue and total costs incurred from each treatment so as to observe if there is a variation among the treatments. These costs and benefits calculated were based on the prices valued for each item in the 2016/2017 cropping season. As a result, the soil test crop response-based fertilizer recommendation returns higher profit margin (306,880.07 ETB/ha) than the other treatments. The blanket type fertilizer application net return was calculated to be 216,387 ETB/ha and the non-fertilized plot (control) returns less (113,400 ETB/ha) than the other treatments.

Generally, the highest net income and Marginal rate of return were gained from STCRB fertilizer recommendation and the lowest net income was from control plots (Table 3). Partial budget analysis revealed that STCRB and blanket fertilizer recommendation were economically feasible at 1355.86 % (MRR) and 1273.46 % (MRR) respectively (Table 3). However, soil test crop response-based fertilizer recommendation was recommended for the study area due to highest net income and MRR. So, farmers and other end users in the study area advised to use this soil test crop response-based recommended fertilizer which is cost effective, economically feasible and environmentally safe.

Table 3. Partial budget analysis

Treatment	Variable Input (Kg ha^{-1})		Unit price (ETB)		TVC	Output (Kg ha^{-1})	Unit price (ETB)	Gross Income (ETB ha^{-1})	Net Income (ETB ha^{-1})	MRR
	DAP	Urea	DAP	Urea						
Control	0	0	0	0	0	1512	75	113400	113,400	
FP	100	100	4008.48	4078.69	8087.17	2993	75	224475	216,387	1273.46
STCRBFR	152.49	200	6112.55	8157.38	14269.93	4282	75	321150	306,880.07	1355.86

where ETB = Ethiopian Birr, FP=Farmer Practice, STCRBFR=Soil test crop response-based fertilizer recommendation, TVC = Total Variable Cost, MRR = Marginal Rate of Return.

4. Conclusion and Recommendation

The field experiment was conducted to verify the determined optimum amount of nitrogen (92 kg N ha $^{-1}$), critical P concentration (9.5 ppm) and P requirement factor (14.23) for bread wheat production in Debre Libanos District. An optimum rate of nitrogen (92 Kg N/ha) and soil test-based phosphorus fertilizer recommendation was highly significantly influencing plant height, spike length, biomass and grain yield of wheat crops. Accordingly, the highest plant height, spike length, biomass yield and grain yield were recorded from the application of soil test crop response-based fertilizer recommendation in combination with recommended optimum Nitrogen (Table 2). The economic analysis also showed that the highest net benefit (306,880.07 ETB) was obtained from site specific soil test-based fertilizer recommendation with marginal rate of return 1355.86 which is greater than the acceptable minimum rate of return (100%) (Table 3).

The critical phosphorus levels and the phosphorus requirement factor show a strong positive effect when examined against typical farming methods and control in the area. In general, recommendations for fertilizers that are based on soil analysis provide superior outcomes compared to blanket recommendations and control for Pc and Prf as a strategy for managing soil fertility. Hence, site specific soil test crop response-based fertilizer recommendation could be recommended and thus the determined Pc (9.5 Ppm) and Prf (14.23) for bread wheat production could be demonstrated before scaled up in study area (Debre Libanos District) and transferred to the end users with similar agro-ecologies.

4.1. Future Directions

1) Establish long-term trials to evaluate the sustainability of the recommended fertilizer rates and their effects on soil fertility, nutrient balance, and soil health over time.

2) Investigate the combined use of inorganic fertilizers with organic sources (e.g., compost, vermicompost, crop residues) to improve nutrient use efficiency and maintain soil productivity.

3) Assess the cost–benefit and profitability of the soil test crop response-based fertilizer recommendation and evaluate farmers' willingness to adopt the technology.

4) Develop soil fertility and fertilizer recommendation maps using GIS for areas with similar agro-ecological conditions, helping extension workers provide location-specific recommendations.

5) Study how climate variability (rainfall and temperature) influences nutrient response of wheat and adjust fertilizer recommendations accordingly.

6) Conduct large-scale on-farm demonstrations and training programs for farmers and extension agents to enhance awareness and proper implementation of soil test-based fertilizer recommendations.

Declarations

Source of Funding

This study was funded by the Oromia Agricultural Research Institute (OARI) and Fitche Agricultural Research Center.

Competing Interests Statement

The authors have not declared any conflict of interest.

Consent for publication

All authors have reviewed and approved the final version of the manuscript and consent to its submission and potential publication. Authors confirm that the work is original, has not been published elsewhere, and is not under consideration by any other journal.

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Dejene Getahun, Dereje Girma and Meron Tolesa. The first draft was written by Dejene Getahun, and all authors commented on previous versions. All authors read and approved the final manuscript.

Informed Consent

Not applicable for this study.

Availability of data and material

Supplementary information is available from the authors upon request.

Institutional Review Board Statement

Not applicable for this study.

Ethical Approval

The experiments conducted in this study comply with the current laws and regulations of Ethiopia regarding agricultural research and pesticide application. No ethical approval was required, as the study did not involve human participants, vertebrate animals, or biological materials requiring such oversight. All field trials were performed in accordance with environmental safety standards to minimize ecological impact. Therefore, no consent to participate was required or obtained.

Acknowledgement

The authors express gratitude to the Fitche Agriculture Research Centre for help with logistics and the Oromia Agricultural Research Institute for financial support. The authors would also like to thank the members of the Soil Fertility Improvement and Problematic Soil Research Team for their proactive involvement in this study and the soil laboratory staff for providing them with the valuable soil analysis data.

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