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Verification of Soil Test Crop Response Based Phosphorus Recommendation on Bread Wheat (*Triticum aestivum* L.) in Leka-Dulacha District, Eastern Wollega Zone, Western Ethiopia

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Abstract

Bread wheat is a major cereal crop cultivated in Ethiopia. Owing to soil fertility depletion, particularly phosphorus (P) deficiency in high-rainfall areas, wheat productivity remains suboptimal in the study area. This study was conducted to verify soil test crop response-based phosphorus fertiliser recommendations for bread wheat in Leka-Dulacha District, extrapolated from the adjacent Jima-Arjo District. A field experiment was laid out in a randomised complete block design with three treatments: control, farmers' practice, and soil test crop response-based P fertiliser recommendation, each replicated three times. The initial soils at the experimental sites were very strongly acidic, with pH values ranging from 4.55 to 4.99, low available P ranging from 3.95 to 12.14 mg kg^{-1} soil, and moderate organic carbon and total nitrogen contents. The soil

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test crop response-based P fertiliser recommendation significantly ($p \leq 0.001$) increased plant height, spike length, number of seeds per spike, number of effective tillers, biomass yield, and grain yield. The reported grain yield reached 29,300 kg ha^{-1}, representing a 74.41% increase over farmers' practice. Economic analysis showed the highest net benefit of ETB 126,487 ha^{-1} and a marginal rate of return of 449.00% under the soil test crop response-based recommendation. These results indicate that extrapolating the calibrated phosphorus recommendation from Jima-Arjo to Leka-Dulacha was agronomically effective and economically profitable under the study conditions.

Keywords: Bread wheat; Critical phosphorus; Economic profitability; Extrapolation; Farmers' practice; Phosphorus requirement factor; Site-specific fertilisation; Soil acidity; Soil test crop response.

1. Introduction

Bread wheat (*Triticum aestivum* L.) is one of the most important cereal crops in Ethiopia. Its broad adaptability to different environmental conditions makes it suitable for cultivation across a range of agro-climatic zones. It is an important cereal crop consumed in various forms in Ethiopia and elsewhere in the world (Kelemu, 2017). In Ethiopia, bread wheat ranks third in area coverage after tef and maize and second in productivity after maize (Ethiopian Statistical Service [ESS], 2022a). Ethiopia is the largest wheat producer in sub-Saharan Africa, accounting for approximately 65% of regional production. Within the country, the largest share of wheat is produced in Oromia (53% of the wheat area and 57% of production), followed by Amhara (34% of the area and 29% of production), the Southern Nations, Nationalities, and Peoples' Region (8% of the area and 8% of production), and Tigray (5% of the area and 6% of production) (ESS, 2022a). Recently, Ethiopia launched a wheat initiative to increase production and substitute wheat imports. To meet national wheat demand and improve self-sufficiency, the Government of Ethiopia has promoted expansion of the cultivated area, advances in irrigation, closure of yield gaps through improved technology adoption, and agro-clustering of smallholder farmers (Effa et al., 2025).

Wheat is cultivated annually on approximately 2.27 million ha, comprising 1.87 million ha under rain-fed production and 0.40 million ha under irrigation, with a total grain production of 7.4 million tonnes. Of this production, 5.8 million tonnes are obtained under rain-fed conditions and 1.6 million tonnes under irrigation, with average productivities of 3.1 and 4.0 t ha^{-1}, respectively (ESS, 2022a). These values remain below the approximately 5 t ha^{-1} achieved at research stations (Mollasadeghi & Shahryari, 2011). Low wheat yield in Ethiopia is primarily associated with soil fertility depletion caused by erosion of surface soil, cultivation of nutrient-exhaustive crops, continuous intensive cultivation, failure to return crop residues to farmland, and minimal or suboptimal fertiliser application (Shanka et al., 2018). Nitrogen and phosphorus are the first and second most yield-limiting nutrients, respectively. For many years, farmers in Ethiopia have commonly followed blanket, and in some locations agronomic, recommendations for urea and diammonium phosphate despite spatial and temporal variability in soils and agro-ecological conditions (Zeleke *et al.*, 2010). The blanket recommendation of 100 kg ha^{-1} N and 100 kg ha^{-1} P_2O_5 may create nutrient imbalances through over- or under-application and may not support optimum crop growth or productivity. Research on soil test-based nutrient application is still at an early stage in Ethiopia, although several studies have been conducted for different crops (Agegnehu & Lakew, 2013; Agegnehu *et al.*, 2015). Researchers have reported that crop yield, including the yield of different varieties of the same species, varies with agro-ecological conditions such as soil and climate, and that soil test crop response-based fertiliser application can improve yield in Ethiopia (Gebremeskel *et al.*, 2015; Agegnehu & Lakew, 2013; Reda, 2016; Chala *et al.*, 2018). Therefore, agro-ecology-based, site-specific soil test crop response recommendations, including phosphorus recommendations, are necessary for efficient fertiliser use and for protecting end users from unnecessary costs (Belissa & Hassan, 2005). Agro-ecology-related soil test-based fertiliser application provides an economically and environmentally sound basis for fertiliser decisions. Accordingly, determining site-specific nutrient rates for a particular soil and crop can improve nutrient-use efficiency and meet crop requirements. Recent field evidence indicates that soil test crop response-based fertiliser recommendations can improve wheat yield, nutrient uptake, and profitability compared with general recommendations and farmers' practice (Dogra *et al.*, 2024). Approaches that improve soil phosphorus availability and plant uptake have likewise been reported to enhance wheat yield-related performance (Jyoti & Shivhare, 2025). The magnitude of wheat response to phosphorus fertilisation varies among soils because inherent soil properties regulate phosphorus availability and uptake, supporting the use of soil-specific nutrient recommendations (Rao *et al.*, 2025). Recent evidence from the Ethiopian highlands further indicates that economically optimal nitrogen and phosphorus rates are location-dependent, emphasising the need for locally validated recommendations (Mulat *et al.*, 2026). A soil test crop response-based phosphorus calibration study was therefore conducted for bread wheat in Jima-Arjo District from 2019 to 2021. The critical phosphorus value (Pc) and phosphorus requirement factor (Pf) were identified as 13 and 9.1 mg kg^{-1} soil, respectively, while the optimum nitrogen rate was 92 kg ha^{-1}. Jima-Arjo and Leka-Dulacha are adjacent districts with similar agro-ecological conditions in terms of soil, the amount and distribution of mean annual rainfall, and minimum and maximum temperatures; consequently, the recommendation was extrapolated to Leka-Dulacha District. However, the applicability of the calibrated critical phosphorus value and phosphorus requirement factor from Jima-Arjo has not been adequately verified under farmers' field conditions in Leka-Dulacha. This evidence gap necessitates local validation before the recommendation can be promoted confidently in the target district. Therefore, the objective of this study was to verify the Pc and Pf values for bread wheat production in Leka-Dulacha District.

2. Materials and Methods

2.1 Description of the Study Area

The experiment was conducted on seven farmers' fields in Leka-Dulacha District for two consecutive cropping seasons (2023/24 and 2024/25) to verify the Pc and Pf values identified for bread wheat in Jima-Arjo District. Leka-Dulacha District is located in the East Wollega Zone of western Oromia Regional State. The district lies between 36°29′ and 37°38′ E and between 8°27′ and 9°29′ N. Its altitude ranges approximately from 1,300 to 3,000 m above sea level, and it has an area of approximately 4,200 km² and a population of 103,023, comprising 49.6% males and 50.4% females (Ethiopian Statistical Service [ESS], 2022b). Leka-Dulacha District has four traditional agro-ecological zones: highland (Baddaa), covering 37.4%; midland (Badda-Daree), covering 35.9%; lowland (Gammoojjii), covering 20.9%; and cold high-mountain areas, covering 5.8%. The dominant soil types are Nitisols (50%), Acrisols (35%), and Cambisols (15%). Mixed crop-livestock production is the predominant farming system. The major crops grown in the district include tef [*Eragrostis tef* (Zucc.) Trotter], bread wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), sesame (*Sesamum indicum* L.), barley (*Hordeum vulgare* L.), faba bean (*Vicia faba* L.), and coffee (*Coffea arabica* L.). Rainfall is monomodal and ranges from 1,500 to 2,500 mm, while the mean minimum and maximum temperatures are 16.7 and 37.8 °C, respectively. Gatama, the capital of Leka-Dulacha District, is located approximately 358 km west of Finfinnee and 28 km south-west of Nekemte. The town is situated at 8°54′ N and 36°32′ E, at an altitude of 2,142 m above sea level.

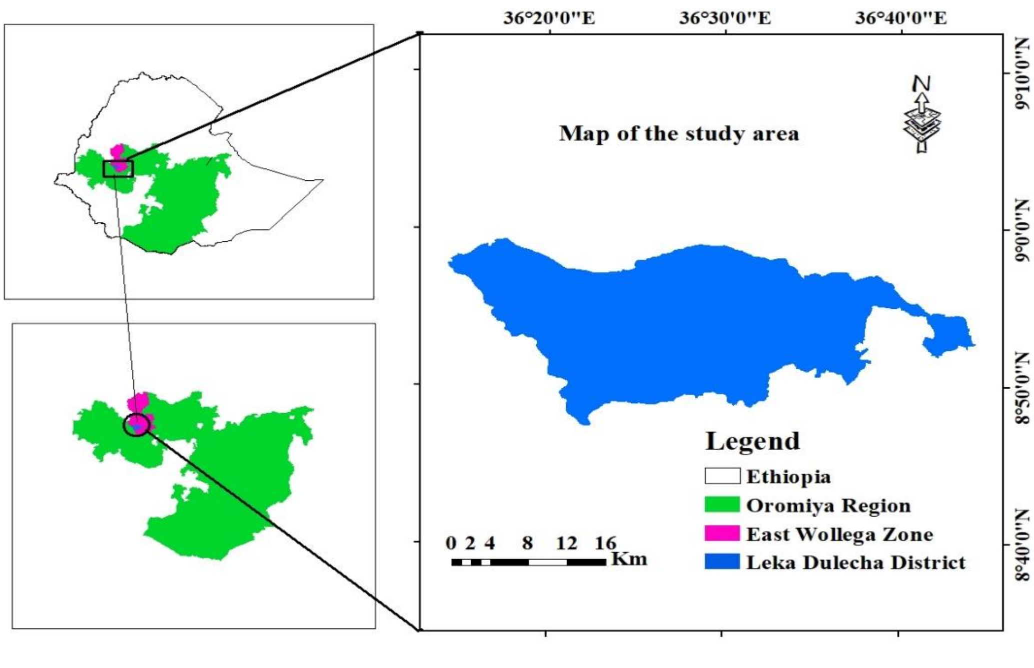

Fig. 1. Map of the study area

2.2 Experimental Materials, Treatments and Design

The experimental materials included the improved wheat variety "*Galan*", urea (46% N), and diammonium phosphate (DAP; 46% P_2O_5 and 18% N). The experiment comprised three treatments: a control without fertiliser, farmers' practice (FP; 146 kg N and 46 kg P_2O_5), and a soil test-based phosphorus recommendation (STBPR; based on Pc and 92 kg N ha^{-1}). The treatments were arranged in a randomised complete block design and replicated three times. The gross plot size was 10 m × 10 m (100 m^2). The spacing between plots and blocks was 0.5 and 1.0 m, respectively.

2.3 Experimental Procedures

During the third week of July in the 2023/24 and 2024/25 cropping seasons, the improved bread wheat variety "*Galan*" was sown. The land was cultivated four times using oxen, in accordance with farmers' practice, to loosen the soil and prepare it for wheat planting. Wheat seed was drilled at a rate of 150 kg ha^{-1} (1.5 kg plot^{-1}), with an inter-row spacing of 20 cm. The recommended amount of DAP for both FP and STBPR was applied once at planting, whereas the recommended amount of urea for both treatments was applied in two equal splits: half at planting and half at the tillering stage. Weeds were removed manually whenever necessary.

2.4 Data Collection

Soil data: Representative composite soil samples were collected from each farmer's field before planting to determine the initial soil nutrient status. Approximately 15 subsamples were collected across each field from a depth of 0–20 cm using an auger and a zigzag sampling pattern. The subsamples were thoroughly mixed on a plastic tray, and approximately 1 kg of composite soil was obtained by quartering and transported to the Nekemte Soil Research Centre for laboratory analysis. The samples were air-dried at room temperature, ground, and passed through a 2-mm mesh sieve. Selected chemical properties, including soil pH, exchangeable acidity, organic carbon, total nitrogen, and available phosphorus, were analysed using standard procedures.

Agronomic Data: Plant height was measured from the soil surface to the tip of the plant using a metre rule, based on ten randomly selected mother plants from each plot. Spike length was measured using a metric ruler and expressed as the mean of ten randomly selected mother plants. The number of effective tillers per plant was counted from ten randomly selected plants at physiological maturity. The number of seeds per spike was also recorded as the mean of ten randomly selected plants from each plot. Above-ground biomass and grain yield were determined from the net plot area of 8 m × 8 m (64 m^2).

Economic Analysis: Economic analysis was performed following the CIMMYT partial-budget methodology (CIMMYT, 1988). Grain and straw yields were adjusted downwards by 10% from the field-measured yields. The gross field benefit was then calculated by multiplying the adjusted yields by the average farm-gate prices of grain and straw. Net benefit (NB) was calculated as the difference between the gross field benefit (ETB ha^{-1}) and the total variable cost (TVC; ETB ha^{-1}) for each treatment. Dominance analysis based on net benefits was used to exclude dominated treatments from the marginal rate of return (MRR) analysis. The MRR was calculated as the change in NB divided by the change in TVC. A non-dominated treatment with an MRR of at least 100% and the highest net benefit was considered economically profitable.

2.5 Statistical Analysis

All collected data were subjected to analysis of variance (ANOVA) using SAS version 9.4 (SAS Institute Inc., 2013). Treatment means were compared using the least significant difference (LSD) test at the 5% significance level.

3. Results and Discussion

3.1 Selected Soil Chemical Properties before Planting

The laboratory results for the pre-planting soil chemical properties are presented in Table 1. According to the rating of Murphy (1968), the soil pH at all experimental sites was classified as very strongly acidic. The strongly acidic soil reaction and high aluminium saturation in the study area may be attributable to the depletion of basic cations through leaching under high annual rainfall and the continued application of NH_4-producing fertilisers, which increase the activity of acidic cations (Al^{3+} and H^+) in the soil solution and lower soil pH (Chimdi, 2014). Initial soil available P was rated as low to very low according to Jones (2002). This may be associated with the very strongly acidic nature of the study soils, which promotes the precipitation of P by aluminium and iron oxides and hydroxides, thereby reducing its availability for plant uptake (Kochian *et al.*, 2005). Soil organic carbon and total nitrogen contents in the study area were classified as moderate according to Debele (1982).

Table 1. Chemical property of experimental soil before planting

Site	pH (H_2O)	Avail. P (mg kg^{-1} soil)	OC (%)	TN (%)	Exch. acidity (Cmol(+) kg soil^{-1})
1	4.81	8.26	2.65	0.23	0.60
2	4.90	5.17	3.04	0.26	0.27
3	4.80	9.17	2.45	0.21	0.97
4	4.58	12.14	2.62	0.23	1.17
5	4.55	3.95	2.27	0.20	2.54
6	4.94	6.91	2.56	0.22	4.02
7	4.99	5.11	1.87	0.23	3.31

Avail. P= available P, OC=organic C, and TN=total N

3.2 Effects of Treatments on Yield and Yield-related Parameters

Plant height: Analysis of variance showed that wheat plant height was significantly ($p \leq 0.05$) affected by fertiliser treatment (Table 2). The highest mean plant height was recorded in plots treated with STBPR, followed by those receiving FP, whereas the lowest value was recorded in the control plots. The STBPR treatment increased plant height by 20% and 60% relative to FP and the control, respectively. This response may have occurred because plants receiving the recommended fertiliser rate obtained sufficient N and P to satisfy crop requirements and support optimum vegetative growth. Consistent with this finding, Eshetu *et al.* (2024a) reported a significant increase in plant height under STBPR compared with FP and the control. Husien *et al.* (2023) likewise reported greater plant height under STBPR than under FP, although the difference was not statistically significant.

Spike length: Statistical analysis revealed that wheat spike length was highly significantly ($p \leq 0.01$) affected by treatment application (Table 2). The longest spikes were recorded in plots treated with STBPR, whereas the shortest were recorded in the control plots. As with plant height, this response may have resulted from adequate N and P supply under STBPR and nutrient deficiency in the control, which restricted plant growth. STBPR increased spike length by 60.80% and 40.45% relative to the control and FP, respectively. Similar findings were reported by Eshetu *et al.* (2024a) and Getahun *et al.* (2020), who found that STBPR significantly increased wheat spike length compared with FP and the control.

Number of seeds per spike: Analysis of variance showed that the number of seeds per spike (NSPS) was highly significantly ($p \leq 0.01$) affected by treatment application (Table 2). The greatest NSPS was recorded under STBPR and was statistically comparable with FP, whereas the lowest value was obtained from the control plots. STBPR increased NSPS by 68.96% relative to the control, possibly because adequate soil N and available P reduced nutrient competition among plants. Eshetu *et al.* (2025) similarly reported that STBPR significantly increased the number of seeds per spike in food barley by 24.27% and 59.78% relative to FP and the control, respectively. The greater NSPS under STBPR contributed to the increase in grain yield. In addition, Eshetu *et al.* (2024b) reported a 55.93% increase in the number of seeds per spike of bread wheat under STBPR compared with FP.

Effective tiller number per plant: The number of effective tillers per mother plant is an important yield-contributing agronomic trait. The number of effective tillers per plant (NETPP) was significantly ($p \leq 0.05$) affected by treatment application (Table 2). The highest NETPP was recorded under STBPR, followed by FP, whereas the lowest value was obtained in the control plots. STBPR increased NETPP by 266.67% and 55.29% relative to the control and FP, respectively. Consistent with these results, Eshetu *et al.* (2025) reported that the number of productive tillers per food barley plant increased significantly from 1.97 in the control to 5.94 under

STBPR and from 3.69 under FP to 5.94 under STBPR, contributing to increased yield. Eshetu *et al.* (2024b) also reported a 122.88% increase in productive tillers per bread wheat plant under STBPR compared with FP.

Biomass and grain yields: Analysis of variance showed that both biomass and grain yields were highly significantly ($p < 0.001$) affected by treatment application (Table 2). STBPR increased biomass and grain yields by 310.27% and 463.46%, respectively, relative to the control, and by 61.89% and 74.41%, respectively, relative to FP. The increases in biomass and grain yields under STBPR were associated with the greater spike length, NSPS, and NETPP recorded under this treatment. Similar findings were reported by Shewangizaw *et al.* (2020), Getahun *et al.* (2020), Chimdessa and Takele (2020), Husien *et al.* (2023), and Eshetu *et al.* (2024a), who observed significant increases in bread wheat biomass and grain yields under STBPR as a result of improvements in yield-attributing components.

Table 2. Treatment effects on plant height, spike length, number of seeds per spike, number of tillers per plant, biomass yield and grain yield of bread wheat

Treatment	PH (cm)	SL (cm)	NSPS	NETPP	BY (kg ha^{-1})	GY (kg ha^{-1})
Control	71.00^{c}	5.44^{c}	29.00^{b}	1.08^{c}	1460^{c}	5200^{c}
FP	95.00^{b}	6.23^{b}	36.00^{a}	2.55^{b}	3700^{b}	16800^{b}
RR	114.00^{a}	8.75^{a}	49.00^{a}	3.96^{a}	5990^{a}	29300^{a}
LSD	17.57	0.75	12.7	1.32	980	310
CV	22.35	9.16	12.44	11.56	17.62	13.68

Means followed by the same letter along columns are not significantly differ from each other at 5% probability level. PH= plant height, SL= spike length, NSPS=number of seeds per spike, NETPP=number of effective tillers per plant, BY=biomass yield, and GY= grain yield

3.3 Economic Analysis

Economic analysis showed that the maximum net benefit of ETB 126,487 ha^{-1}, with an MRR of 449.00%, was obtained from the soil test crop response-based phosphorus fertiliser treatment (Table 3). According to CIMMYT (1988), a treatment with an MRR greater than 100% and the highest net benefit is considered economically profitable and may be selected for recommendation in the study area. Accordingly, the soil test crop response-based phosphorus fertiliser treatment was identified as the economically profitable option. This result indicates that each ETB 1 invested generated an additional net return of ETB 4.49.

Table 3. Economic analysis for treatments

Treat	Urea (kg/ha)	NPS (kg/ha)	GFB (birr/ha	TVC (birr/ha)	NB (birr/ha)	MRR (%)
Control	0	0	41094	3424.5	37669.5	-
FP	100	100	104652	12921	91731	569.28
STBPR	200	200	147150	20662.5	126487.5	449.00

Where FP = Farmers practiced; STBPR = soil test crop response-based fertilizer recommendation; GFB = Gross field benefit; TVC =Total variable cost; NB = Net benefit and MRR = Marginal rate of return. While the price of urea, NPS and wheat were 42, 40, 60 birr/kg respectively

4. Summary and Conclusion

The results showed that the initial soils at all experimental sites were very strongly acidic, with low plant-available P and elevated levels of potentially toxic cations such as aluminium and iron. All measured agronomic parameters, including plant height, spike length, number of seeds per spike, number of effective tillers per mother plant, biomass yield, and grain yield, were significantly affected by treatment application. Soil test crop response-based P fertiliser application produced significant improvements over farmers' practice and the control. Compared with farmers' practice, spike length and the number of effective tillers per mother plant increased by 40.45% and 55.29%, respectively, under the soil test crop response-based phosphorus fertiliser treatment, contributing to improved grain yield. Grain yield increased by 74.41% relative to farmers' practice. Economic analysis also showed that the soil test crop response-based phosphorus fertiliser treatment produced the maximum net benefit of ETB 126,487 ha^{-1} and an MRR of 449.00%, equivalent to a return of ETB 4.49 for each ETB 1 invested. Site-specific soil test crop response-based fertiliser application can therefore optimise crop yield while reducing unnecessary or suboptimal fertiliser use. Under the conditions of this study, extrapolation of the recommendation developed in Jima-Arjo District to Leka-Dulacha District was agronomically effective and economically profitable.

5. Limitations

The findings are specific to seven farmers' fields evaluated over two cropping seasons in Leka-Dulacha District and to the tested bread wheat variety, soil conditions, and fertiliser treatments. Their applicability beyond comparable agro-ecological and soil conditions should therefore be interpreted cautiously. The verification focused on short-term agronomic and partial-budget outcomes and does not establish long-term effects on soil fertility or sustained profitability. Additional validation across sites and seasons would strengthen the basis for wider recommendation.

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study of design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, and reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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