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Original article

Verification of soil test crop response based calibrated phosphorus for food barely (*Hordeum Vulgare* L.) production in Sinana District, Bale Zone, Oromia Region, Southeast Ethiopia

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ABSTRACT

Nitrogen and phosphorus are the main variables restricting crop productivity in the soil of the study area, especially, in food barely productions. In the Sinana district, soil test-based phosphorus calibration studies were carried out in the past, and fertilizer 46 N kg ha⁻¹, P critical (20 ppm), and P requirement factor (4.60) were recommended for food barely production. To confirm the phosphorus critical (Pc) level and phosphorus requirement factor (pf) found during soil test crop response based phosphorus fertilizer calibration study for food barely production in 2022 bona (July to December) main cropping season, an on-farm field experiment was carried out in this study. The experimental setting comprised three treatments: (1) control (without fertilizer), (2) farmer practices as a blanket recommendation, and (3) soil test crop response-based phosphorus recommendation results. The improved food barely, Adoshe variety was used as a test using farmers as replication in seven sites with 10 m × 10 m plot sizes. Soil samples before planting were taken at 0 - 20 cm soil depth using a random sampling technique and analyzed using standard laboratory procedures. In contrast, the agronomic parameters were analyzed using R software 4.1.1 version. The results show soil sample analysis varied from 6.03 to 6.25, 1.68 to 2.62%, and

ranged from 1.01 to 3.30 mg/kg for soil pH (pH_H2O), OM, and available phosphorus, respectively. The results revealed a significant ($p < 0.05$) difference between food yield and yield components. The soil test crop response-based phosphorus recommendation results yielded the highest grain yield (5682.43 kg ha⁻¹) with a marginal rate of return (4131.16%). Thus, for food barely production in Sinana District, the Pc (20 ppm) and pf (4.60) with optimal N (46 kg ha⁻¹) were verified from this study. It should be recommended that further demonstrate and scale up the application of soil test-based fertilizer recommendations, to extrapolate Pc and Pf for similar soil types, and to determine the adjusted NPS fertilizer rate using calibrated phosphorus for food barely production.

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1. Introduction

Food barley (*Hordeum vulgare* L.) is one of the earliest cereal crops, crucial to the development of agriculture (Malla et al., 2021). Barley is one of the most significant cereal crops in the world, ranked fourth behind rice, wheat, and maize. For many smallholder farmers in the Ethiopian highlands, it is the most significant crop for food production, animal feed, and revenue (Bayeh and Berhane, 2011). However, several problems influence food barely production despite its great significance and utility for economic development and food security (Melle et al., 2015).

In the Ethiopian highlands, low soil fertility, inadequate agronomic techniques, and traditional production methods are the main causes of low barley yields and the most limiting factor for barley production (Abera et al., 2011; Abera et al., 2018; Lake and Bezabih, 2018). Soil fertility issues, flooding, bug and pest infestations, inadequate crop management techniques, and lodging are the primary causes of decreased food barley production.

Due to erosion, leaching, and low nutrient recycling are the possible reasons for poor nutrient contents particularly those in the highlands of Ethiopia soils (Malla et al., 2021). In Ethiopia's highlands, one of the main problems restricting barley production is the depletion of soil fertility (Bayeh and Berhane, 2011; Agegnehu et al., 2011). As a result, improving low soil fertility in the form of nutrient additions from various fertilizer sources is crucial for boosting soil productivity and sustained crop output. In large-scale agricultural regions, phosphorus and nitrogen are the two plant nutrients that are most limiting crop productivity. According to (Ketema and Mulatu, 2018), barley is highly responsive to nitrogen fertilization and extremely sensitive to low nitrogen levels.

Nonetheless, urea, diammonium phosphate (DAP), NPS, and other blended fertilizers are mainly based on a single blanket recommendation, particularly in the study area. This blanket recommendation often does not consider variations in resource soil types, climate risks, ideal agricultural productivity, and the economically significant. Thus, there is an urgent demand for crop response fertilizer recommendations based on soil testing.

The quantity of phosphorus in kilogram required to raise soil phosphorus by 1 mg kg⁻¹ is the phosphorus requirement factor (Pf), and it aids in calculating the amount of P required per hectare to raise soil test levels by 1 mg kg⁻¹ and supply available P levels above the critical level. The amount of phosphorus in the soil that provides the optimum yield response to P treatment is the critical P value (Pc). The critical P value (Pc) is the level of phosphorus in the soil that gives the optimal yield response to P application, but above this value causes a decrease, unpredictability, or zero yields. The critical value of soil P for optimum crop yield varies based on soil type, crop species, and environmental conditions (Walkley and Black, 1934).

As a result, the optimal nitrogen rate (46 N kg ha⁻¹), P critical (20 ppm), and P requirement factor (4.60) for food barely production from the 2019-2021 cropping season were determined by previously conducted soil test-based phosphorus calibration studies in Sinana District (Mulugeta et al., 2022). Therefore, in the district's food barely producing areas, farmers' fields should be used for verification of these technologies before their dissemination, demonstration, and scaling up (Mulugeta et al., 2022). Therefore, this study aimed to verify the critical phosphorus (Pc) and phosphorous requirement factor (Pf) for food barley production in the study area.

2. Materials and Methods

2.1. Description of the study area

The Sinana district, which is 460 kilometers from Addis Ababa. The Sinana is situated between 39°55'0"E and 40°21'0"E and between 6°47'30"N and 7°22'0"N. Topographically, the Sinana district varies from plain to gently sloped, with 1700 to 3100 meters above mean sea level (masl).

2.2. Climate characteristics

The area experiences bimodal rainfall patterns, with yearly totals varying from 453 mm to 1130 mm. Minimum temperatures varied between 6.8 and 10.1 °C, and maximum temperatures ranged from 21.9 to 23.5 °C. Crop farming is the primary source of subsistence income or economic activity. In this area, potatoes predominate among horticultural techniques, along with wheat, barley, faba beans, and field peas.

2.3. Design and arrangement for experimentation

The trial was conducted for a year during the main cropping season in 2022 on the farms of seven farmers. Three treatments were used in the experimental field: blanket recommendations, soil test-based P fertilizer recommendations with an optimal nitrogen rate of 46 kg ha⁻¹, and control (without fertilizer). Sources of fertilizer were urea and TSP for N and P, respectively, and 125 kg ha⁻¹ rate of food barely Adoshe variety on 10 m x 10 m (100 m²) plot size were used.

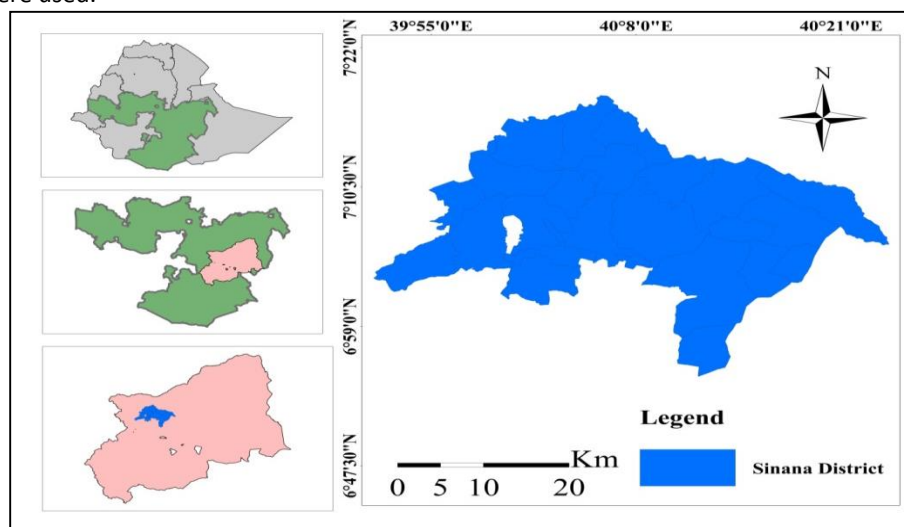


Fig. 1. Map of the study area.

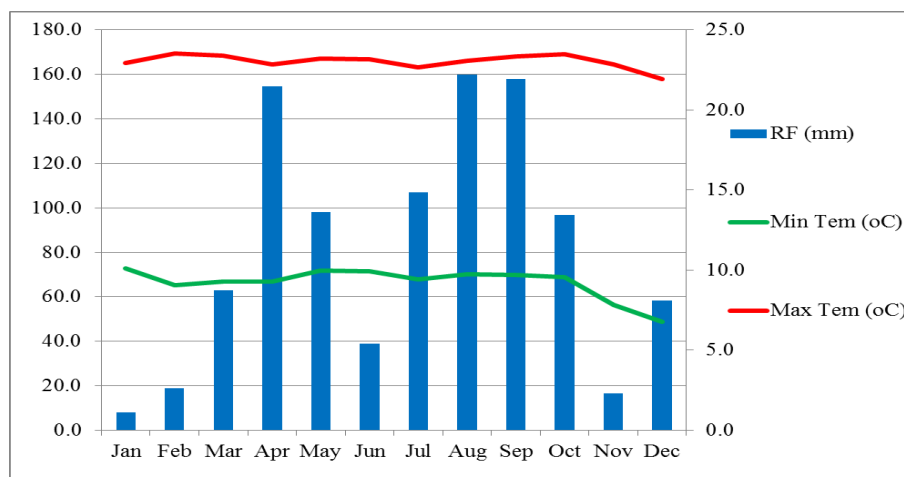


Fig. 2. The Sinana district's average monthly rainfall (mm) and maximum and minimum temperatures (°C).

2.4. Soil sampling and laboratory analysis

Before planting, soil samples were taken from the experimental sites using auger sampling points at 0 - 20 cm soil depth, and composites were prepared. The composite soil samples were labeled with the relevant information, air-dried, and crushed with a mortar and pestle through a 2 mm mesh sieve. The analyses were conducted at the Sinana Agricultural Research Center. A pH meter, was used to determine the soil's pH in the supernatant suspension of a 1: 2.5 soil-to-water ratio (Malla et al., 2021). According (Tekalign, 1991) was used to determine the amount of organic carbon. The Olsen method was used to determine available P (Olsen et al., 1954).

Phosphorus fertilizer rate (kg ha⁻¹) = $P_c - P_i$ * P_f ... (1)

Where, P_f = phosphorus requirement factor (4.60), P_i = initial available phosphorus, and P_c = phosphorus critical level (20 ppm) are for Sinana District.

2.5. Agronomic data collection and analysis

Agronomic data related to food, such as plant height, the number of productive tillers, and the number of seeds per spike, above-ground biomass, and grain yield, were collected and subsequently subjected to statistical analysis. Using R version 4.1.1 software. The LSD at a 5% probability level test for mean separation for significant treatments (Gomez and Gomez, 1984).

2.6. Partial budget analysis

The economic viability of the treatment measures was conducted using a partial budget analysis (Dejene et al., 2020). The average grain yield was adjusted by 10% to reduce the possibility of overestimating the yield when converting a small plot of land's yield to hectares.

3. Result and Discussion

3.1. Selected soils chemical properties before planting

As shown in Table 1, the soil pH (pH_{H2O}) values ranged from 6.03 to 6.25. According to (Jones and Benton, 2003) pH rate, the soil of the study area was classified as a slightly acidic medium. According to Table 1, the range of values for soil organic matter (OM) was 1.68 to 2.62%. According to (Rhoades, 1982), the OM was low to moderate class. The available phosphorus (Av. P) as established by the Olsen technique (Cottenie, 1980), was very low, with values ranging from 1.01 to 3.30 mg/kg (Table 1). The very low category of these important soil plant nutrients might be caused by nutrient fixation, leaching, prolonged monocropping of cereals, poor or limited inputs of organic and inorganic fertilizers, and loss from soil erosion.

Table 1

Selected soils' chemical properties status of experimental sites of Sinana district.

Sites Name	pH (H ₂ O)	OM (%)	Av. P (mg/kg)
1	6.06	1.68	2.29
2	6.25	2.18	1.01
3	6.03	1.94	2.85
4	6.11	1.88	2.51
5	6.2	2.39	2.30
6	6.08	2.22	1.82
7	6.14	2.62	3.30

Where: OM = soil organic matter, Av. P = available phosphorus

3.2. Response of food barely yield and yield components

Based on a statistical examination of all the agronomic data collected, the yield components and yield of food barely were significantly ($p \leq 0.05$) different between different fertilizer recommendations (Table 2). Accordingly, the highest yield components of food barely, namely plant height, spike length, seed per spike, number of tillers, biomass, and TKW were obtained from soil test-based crop response fertilizer recommendation followed by

blanket recommendation, while the lowest from the control (without fertilizer) (Table 2).

The responses on food barely grain yield revealed that the highest (5682.43 kg ha⁻¹) and the lowest (2033.00 kg ha⁻¹) grain yield was recorded from soil test-based crop response fertilizer recommendation and control, respectively. This result confirmed the findings of (Dejene Getahun et al., 2020; Mulugeta et al., 2022; Chimdessa and Takele, 2020; Mulugeta et al., 2017) who reported that soil test-based site-specific optimum fertilizer recommended results the highest grain yield over blanket recommendation.

Table 2

Response of food barley production to verification of soil test crop response based Calibrated in Sinana District.

Treatments	PH (cm)	SL (cm)	SPS	NT	BM (kg/plot)	GY (kg/ha)	TKW (g)
Control	69.4 ^c	3.41 ^c	34.71 ^c	1.97 ^c	45.73 ^b	2033.00 ^c	31.49 ^c
BK	82.6 ^b	5.05 ^b	44.63 ^b	3.69 ^b	65.21 ^{ab}	3410.14 ^b	33.86 ^b
STBFR	98.0 ^a	6.87 ^a	55.46 ^a	5.94 ^a	84.96 ^a	5682.43 ^a	36.19 ^a
Mean	83.33	5.11	44.93	3.87	65.30	3708.52	33.85
LSD (0.05%)	9.61	0.76	4.01	0.99	21.70	306.40	2.32
CV (%)	10.27	13.31	7.94	22.74	29.59	7.50	6.11

Where: BK = blanket recommendation, STBFR = soil test based crop response fertilizer recommendation, PH = plant height; SL = Spike length, SPS = seed per spike, NT = Number of productive tiller, BM = above ground biomass, GY = Grain weight

3.3. Economic analysis

Based on this result, the partial budget analysis indicated that the soil test-based P recommendation is economically feasible for food barely production in the district. Accordingly, the use of soil test-based crop response phosphorus recommendation is advisable having net benefit (150525.61 ETB) with acceptable MRR (4131.16%) for food barely production in the Sinana district.

Table 3

Partial budget analysis for verification of soil test crop response based Calibrated phosphorous for food barely production in Sinana district.

Treatment	UnGY (Kgha ⁻¹)	AGY (Kgha ⁻¹)	GB (Birrha ⁻¹)	TVC (Birrha ⁻¹)	NB (Birrha ⁻¹)	MRR (%)
Control	2033	1829.7	54891	0	54891	0
BK	3410.14	3069.126	92073.78	1450	90623.78	2464.33
STBFR	5682.43	5114.187	153425.61	2900	150525.61	4131.16

Where, BK = blanket recommendation, STBFR = soil test-based crop response fertilizer recommendation, AGY = adjusted grain yield, GB = gross benefit, UnGY = unadjusted Grain yield, TVC = total variable cost, NB = net benefit, MRR = marginal rate of return.

Table 4

Farmer's perception and selection criteria.

Treatments	Rank	Reason for selection (criteria)
Control	3 rd	
BK	2 nd	
STBFR	1 st (100%)	Highest seed per spike, spike length, plant height, more productive tiller, good standing and expected high grain yield.

Where; BK = blanket recommendation, STBFR = soil test based crop response fertilizer recommendation

3.4. Farmer perception

The experiment was ranked based on the farmer's preference perception and selection criteria (Table 4). Accordingly, 55 farmers were used to select and evaluate based on their knowledge, and own criteria then finally verify the experiment. Table 4. Farmer's perception and selection criteria.

4. Conclusion

In conclusion, soil test crop response-based fertilizer recommendations significantly increased food barely production compared to blanket recommendations. As a result, the optimal nitrogen rate (46 kg ha^{-1}), the critical value of P concentration (P_c) (20 ppm), and the value of the phosphorus requirement factor (P_f) (4.60) have been verified for food barely production in Sinana district, and extrapolate for similar soil types areas. The highest food barely grain yield ($5682.43 \text{ kg ha}^{-1}$) with an economically feasible and acceptable marginal rate of return (4131.16 %) from a soil test-based fertilizer recommendation.

Therefore, verified optimum nitrogen (46 kg ha^{-1}), P_c (20 ppm), and P_f (4.60) should be advisable for food barely production in the Sinana district, and similar soil types. Based on these results, demonstrations, and scale-up of soil test-based fertilizer applications are needed. Further studies on determining adjusted NPS fertilizer rates using P_c and P_f based on calibrated phosphorus for food barely production should be encouraged.

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Conflicts of Interest

The authors declare no conflicts of interest.

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