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Research Article

Verification of soil test crop response based calibrated phosphorous for Food Barely (*Hordeum vulgare* L.) production in Sinana District of Bale Zone, Oromia Region, Southeastern Ethiopia

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ABSTRACT

Nitrogen and phosphorus fertilizers are the major limiting factors for crop production in soils of the study area. In previous years' soil test-based phosphorus calibration studies were conducted in the Sinana district, and 46 N kg ha^{-1}, P critical (4.60 ppm), and P requirement factor (20 ppm) were recommended for food barely production. In this study, an on-farm field experiment was conducted to verify the Phosphorus Critical (Pc) level and Phosphorus requirement factor (pf) determined during soil test crop response based phosphorus fertilizer calibration study for food barely production in 2022 bona (July to December) main cropping season. The treatments and experimental setup included (1) Control (without fertilizer), (2) Blanket recommendation (farmer practices), and (3) Soil test crop response-based phosphorus recommendation results.

Improved food barely Adoshe variety used as test crop on 10 m x 10 m plot sizes at seven sites using farmers as replicates. Soil samples before planting were taken at 0–20 cm soil depth using random sampling and analyzed using standard laboratory procedures. Agronomic parameters of food barely were collected and analyzed using R software version 4. 1.1 software. 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-H_2O), OM, and available phosphorus, respectively. The statistical analysis shows a significant ($p \leq 0.05$) difference among yield and yield components of food barely. As a result, the highest grain yield (5682.43 kgha^{-1}) with an acceptable marginal yield rate of return (4131.16%) was obtained from soil test crop response-based phosphorus recommendation results. Therefore, from this study, the Pc (4.60 ppm) and pf (20 ppm) with optimum N (46 kgha^{-1}) were verified for food barely production in Sinana District. Further demonstration and scale-up of soil test-based fertilizer recommendation, extrapolation Pc and Pf for similar soil types as well as determining the adjusted NPS fertilizer rate based on calibrated phosphorus for food barely production should be recommended.

Keywords: Blanket fertilizer application, Food barely production, Optimum nitrogen, P Critical, P Requirement factor, Soil-test based fertilizer application

INTRODUCTION

Food barley (*Hordeum vulgare* L.) is one of the oldest cereal crops and plays an important role in the development of agriculture (Malla et al., 2021). Barley is one of the most important cereal crops in the world, ranking fourth in production areas next to wheat, maize, and rice (USDA, 2017). It is the most important crop for food, animal feed, and income generation for many smallholder farmers in the Ethiopian highlands (Bayeh and Berhane, 2011). Despite barely production high importance and usefulness for food security and economic development, it is influenced by several factors (Melle et al., 2015). The potential for barely production at national and regional productivity levels is just under 1.3 t ha^{-1} (CSA, 2015).

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The most limiting factor for barley production in the Ethiopian highlands and causes for low barley yields are mainly due to traditional production methods, poor agronomic practices, and low soil fertility (Abera et al., 2011, Assefa et al., 2017, Lake and Bezabih, 2018 and Abera et al., 2018). Accordingly, the main factors that reduce food barley yields are poor soil fertility, waterlogging, pests and insects, poor crop management practices, and lodging.

Most Ethiopian soils, especially in the highlands, are low in nutrient content due to erosion, leaching, and the absence of nutrient recycling (Malla et al., 2021). Soil fertility depletion is among the most important limiting factors for barley production in the highlands of Ethiopia (Bayeh and Berhane, 2011 and Agegnehu et al., 2011). Consequently, the addition of nutrients from different sources of fertilizer to low soil fertility is important to enhance sustainable crop production and soil productivity. Among other plant nutrients nitrogen, and phosphors are the most limiting nutrient for crop production in major agricultural areas. Barley is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization (Ketema and Mulatu, 2018). Therefore, adopting good nutrient management strategies often brings significant economic benefits to farmers.

However, fertilizer recommendations in Ethiopia, especially in the study area, are mainly based on a single blanket recommendation of nitrogen and phosphorus fertilization in the form of urea, diammonium phosphate (DAP), NPS, and other blended fertilizers. This blanket recommendation often does not consider differences in resource soil types, climate risks, optimal agricultural production, and the economically relevant. Therefore, soil testing-based crop response fertilizer recommendations are urgently needed.

The phosphorus requirement factor (pf) is the amount of phosphorus in kg needed to increase soil phosphorus by 1 mg kg^{-1}, which helps determine the amount of P needed per hectare to increase the soil test by 1 mg kg^{-1} to provide available P levels above the critical level. The critical P value (Pc) is the level of phosphorus in the soil that gives the optimal yield response to P application in which above this value, yields are decreasing, unpredictable, or zero. The critical value of soil P for potential crop yield, which varies depending on soil type, crop species, and environmental factors, is defined as the soil P content above which no potential productivity (Tang et al., 2009, Shi et al., 2015 and Hu et al., 2021).

Accordingly, previous conducted soil test-based phosphorus calibration studies in Sinana District for food barely production from the 2019 -2021 cropping season and optimum nitrogen rate (46 N kg ha^{-1}), P critical (4.60 ppm) and P requirement factor (20 ppm) were determined (Mulugeta et al., 2022). Thus before disseminating, demonstrating, and scaling up these technologies should be verified on farmers' fields for food barely production areas in the district (Mulugeta et al., 2022). Therefore, the purpose of this study was to verify the critical phosphorous (Pc) and phosphorous requirement factor (Pf) for food barley production in the study area.

MATERIALS AND METHODS

Descriptions of the study area

The experiment was conducted in the Sinana district, about 460 kilometers from the capital Addis Ababa. Geographically, the Sinana area is located between 6°47'30"N and 7°22'0"N and 39°55'0"E and 40°21'0"E. Topographically, the district consists of a gently undulating plain with an altitude of 1700 to 3100 above mean sea level (masl) (Figure 1).

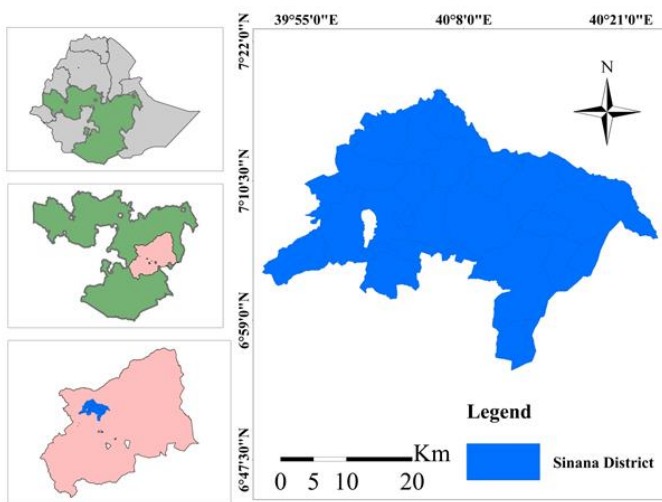

Figure 1. Map of the research site.

Climate characteristics

The rainfall pattern in the area is bimodal and is characterized by annual rainfall ranging from 453 mm to 1130 mm. Maximum temperatures ranged from 21.9 to 23. 5°C, while minimum temperatures varied between 6.8 and 10.1°C. Agriculture is the main economic activity in this area, and crop cultivation is the main source of subsistence income. The main crops grown in this area include wheat, barley, faba beans, and field peas, and potato is dominant among horticultural practices (Figure 2).

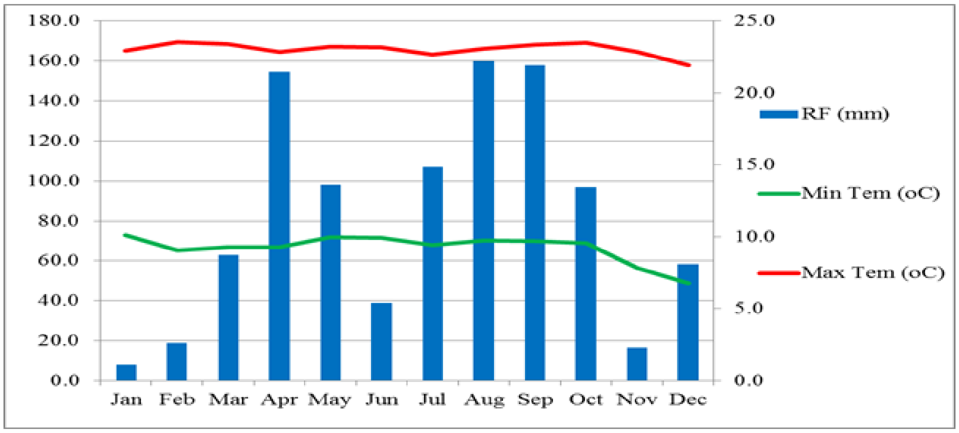

Figure 2. Average monthly precipitation (mm), maximum and minimum temperature (°C) in Sinana district.

Experimental design and layout

The experiment was conducted on 7 (seven) farmers' fields in the 2022 main cropping season for one year. The experimental field was arranged with a total of 3 treatments *viz.* control (without fertilizer), blanket recommendation, and soil-test based P fertilizer recommendation with optimum nitrogen rate (46 kg ha^{-1}). Fertilizer sources for N and P urea and TSP, respectively; with 125 kg ha^{-1} improved food barely Adoshe variety in plot size was 10 m × 10 m (100 m^2) were used.

Soil sampling, preparation, and laboratory analysis

Soil samples at 0- 20 cm depth were taken from the experimental sites before planting using auger sampling points and composites were prepared. The composite soil samples were labeled with necessary information then air dried and crushed using a mortar and pestle to pass through a 2 mm mesh sieve for most soil physicochemical properties. The initially available phosphorus below critical concentration determined for the district was selected for the experiment. The analyses were conducted at Sinana Agricultural Research center based on standard laboratories procedure for each parameter.

Particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). Finally, the textural class of the soil was assigned using the USDA textural triangle classification system (USDA, 1987). The pH of the soil was measured in the supernatant suspension of a 1:2.5 soil-to-water ratio using a pH meter (Rhoades, 1982). (Walkley, 1934) the method was used for the determination of organic carbon. Total nitrogen was determined using the Kjeldahl method as described by (Bremner and Mulveny, 1982). Available P was determined following the Olsen method Olsen (1954) using ascorbic acid as a reducing agent. Then Phosphorus fertilizer requirement was calculated for each farmer by using the formula:

$$\text{Phosphorus fertilizer rate}\left(\frac{\text{kg}}{\text{ha}}\right) = (\text{Pc} - \text{Pi}) \times \text{Pf} \qquad (1)$$

Where, Pc-phosphorus critical level 4.60 ppm, Pi- Initial available phosphorus, Pf-phosphorus requirement factor 20 for Sinana District.

Agronomic data collection

The food barely gronomic data were such as plant height, numbers of productive tillers, seed per spike, above-ground biomass yield; and grain yield, were taken and then finally subjected to standard statistical analysis. The LSD at a 5% probability level test was used for mean separation for significant treatments using R software 4.1.1.

Statistical analysis

The collected food barely yields and yield component data were subjected to analysis of variance (ANOVA) using R software version 4.1.1. Significant differences among treatment means were separated by Least Significant Differences (LSD) at a 5% level of probability and using a linear correlation coefficient matrix. Based on these, interpretations were made following the procedure described by (Gomez and Gomez, 1984).

Partial budget analysis

A partial budget analysis was performed to determine the economic feasibility of the treatment measures (CIMMYT, 1988). The average grain yield was also adjusted by a 10% reduction to minimize overestimation of yield when the yield of a small plot of land was converted to hectares.

RESULTS AND DISCUSSION

Selected soils chemical properties before planting

The soil pH (pH-H_2O) values varied from 6. 03 to 6.25 as indicated (Table 1). As per the pH ratings suggested by Jones (2003) pH in soil-water ratio was rated slightly acidic media. The values of soil organic matter (OM) were ranged from 1.68 to 2.62 % (Table 1). As per the ratings of Tekalign (1991) OM contents for soils of the experimental sites rated into low to moderate class. The values of available Phosphorus (Av. P) ranged from 1.01 to 3.30 mg/kg which rated very low based on the critical values as determined by the Olsen method (Cottenie, 1980). The very low categories of these major soil plant nutrients might be due to leaching, continued cereal monocropping, low or limited inputs of organic and inorganic sources of fertilizers, nutrient fixation, and loss due to soil erosion.

Table 1. Selected soils' physicochemical properties status of experimental sites of Sinana district.

Sites name	pH (H_2O)	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	2.3
6	6.08	2.22	1.82
7	6.14	2.62	3.3

Note: OM=soil Organic Matter, Av. P=Available Phosphorus

Response of food barely yield and yield components

The statistical analysis of all agronomic data collected indicated that there was a significant difference ($p<0.05$) between different fertilizer recommendations on bread wheat yield and yield components. 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 et al. (2020); Temesgen and Chalsissa (2020) and Mulugeta et al. (2022) 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	65.3	3708.52	33.85
LSD (0.05%)	9.61	0.76	4.01	0.99	21.7	306.4	2.32
CV (%)	10.27	13.31	7.94	22.74	29.59	7.5	6.11

Note: 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 Yield; TKW: Thousand Kernel Weight

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).

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	153425.6	2900	150525.6	4131.16

Note: BK: Blanket recommendation; STBFR: Soil Test-Based crop response Fertilizer Recommendation; UnGY: Unadjusted Grain yield; AGY: Adjusted Grain Yield; GB: Gross Benefit; TVC: Total Variable Cost; NB: Net Benefit; MRR: Marginal Rate of Return

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.

Table 4. Farmer's perception and selection criteria.

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

Note: BK: Blanket recommendation; STBFR: Soil Test Based crop response Fertilizer Recommendation

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 (Pc) (4.60 ppm), and the value of the phosphorus requirement factor (Pf) (20 ppm) 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 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}), Pc (4.60 ppm), and Pf (20 ppm) 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 Pc and Pf based on calibrated phosphorus for food barely production should be encouraged.

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CONFLICT OF INTEREST

The author declares that they have no competing interests in all aspect regarding this research article.

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