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Verification of Phosphorus Recommendations Based on Soil Test Crop Response for Maize (*Zea mayis L.*) in Boneya Boshe District, Western Oromia, Ethiopia

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Abstract

Verification trials of maize phosphorus recommendations based on crop response to soil tests were conducted in the Boneya Boshe district of Western Oromia during the 2021 main cropping season. The purpose of this study was to extrapolate and verify previous validation results for maize in Bako Tibbe and Gobu Sayo districts as benchmark based on soil test crop response and recommended Pc and Pf. A critical P-value (14.5) and a P-requirement factor (5.5) were adopted for maize in this district. In this study three treatments were used: T1 (Control), T2 (STBFR), T3 (Farmers practice), using an improved Maize variety (BH-546) were arranged side by side with simple adjacent plots and replicated over eleven farmers' fields in the district. Plot size for each treatment was 10 m x 10 m (100 m^2). The highest average grain yield (6520 kg/ha) was obtained from the soil test crop response based on fertilizer recommendations, while the lowest average grain yield (1515.62 kg/ha) was recorded from the control plot. Ultimately, the partial budget analysis also showed that the critical and requirement factors for phosphorus are economically feasible with a net benefit of (92,900 Birr) and an MRR of 2144%. Therefore, Pc and Pf are verified and recommended to farmers in Boneya Boshe to produce maize and obtain optimal yields, while further scale-up is expected to promote this technology to farmers in the study area and similar agro-ecologies.

Keywords: Phosphorus; Farmers practices; P-Critical; P-requirement factor; Soil test based; Verification

Introduction

Fertile soil is declining in many African countries. Crop production in Ethiopia has felled and productivity has declined rapidly (Dubale, 2001). In rural Africa, soil fertility is declining and artificial and natural fertilizers are used to replenish subsurface soil nutrients (Itelima et al., 2018). Thus, cereals and cash crop require a variety of nutrients to grow healthily. Food insecurity in Ethiopia and other parts of Africa is a major socio-political issue. Its economic well-being also depends on agricultural success. Maize is one of the most important cereal crops of the world (Awika, 2011) and it is largely produced in Western, Central, Southern and Eastern parts of Ethiopia (Abera et al., 2018). Although Ethiopia has a wide range of crops and agro-ecological diversity, it has long suffered from food shortages and economic underdevelopment and Maize, tef (Eragrostis tef), sorghum, wheat and barley are among cereals and Enset (Ensete ventricosum) among roots and tubers provide the major caloric requirements in the Ethiopian diet (Abate et al., 2015). Crop productivity and yields remained low and erratic throughout much of the 1990s, but there have been clear signs of change in the past decade (Piesse and Thirtle, 2009) [1]. Since its introduction to the continent around 1500 AD, maize has rapidly expanded across Africa and transformed production systems as a popular and widely grown food crop (Abate et al., 2015). Maize arrived in Ethiopia somewhat later, around the end of the 17th century (Huffnagel, 1961), and was grown mainly as a subsistence crop in the mid-altitude areas of the south, south-central and southwest (1500-2000 m above sea level). Parts of the country (Abate et al., 2015) [2]. The production system in the 1960s and first quarter of the 1970s was indeed self-sufficient, with yields barely exceeding 1 metric ton (MT)/ha. After the severe drought in 1974, the area growth rate declined, and although there was some expansion in the 1980s, the average annual yield fluctuated greatly, rarely exceeding 1.5 metric tons/ha (Abate et al., 2015) [3]. Maize production and its place in determining the country's food security came into focus in the mid-1980s, particularly spurred by the devastating drought of 1984 and subsequent famine (Abate et al., 2015). The crop's broad adaptability and potential to produce more calories and food per unit of arable land than all major cereals grown in Ethiopia are important factors in considering the inclusion of maize in national food security strategies, including its inclusion in government-led intensive agricultural programmes (Dessie, 2018). As increased production drives down market prices, maize becomes cheaper for rural and urban consumers (for example, relative to other staples such as teff and wheat). (Crymes, 2015). Maize is the most important staple food in terms of calorie intake in rural Ethiopia [4,5]. The 2004/5 National Consumer Expenditure Survey shows that among the main cereals, maize accounts for 16.7% of the country's caloric intake, followed by sorghum (14.1%) and wheat (12.6%) (Dessie, 2018). Compared with the1960s, maize's share of cereal consumption has more than doubled to nearly 30% with the 2000s, while the share of teff - the largest cereal among all crops in Ethiopia - has dropped from over 30% to around 18% over the same period (Abate et al., 2015). Maize's popularity in Ethiopia is driven in part by its high value as a food crop, as well as growing demand among rural households for the straw as a source of animal feed and fuel (De Groote et al., 2013). Approximately 88% of the maize produced in Ethiopia is consumed as food, including green cereals and dry grains. Industrial corn also supports growing demand (Assefa, 2018) [6,7].

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Currently little maize is used as feed, but this is changing to support rapid urbanization and the poultry industry (Hellin and Erenstein, 2009). Unlike its neighbor Kenya, which imports a large part of its consumer needs, Ethiopia has gradually become self-sufficient in maize production since the beginning of this century, even exporting to neighboring countries such as Sudan and Djibouti in cases of excess production (Woube, 2005) [8].

Soil fertility refers to the ability of the soil to sustain crop growth- the ability to provide habitat for plants and produce sustainable, uniform, high-quality products) [9]. It also refers to the soil's ability to continuously supply plant and crop nutrients in sufficient quantity and quality (El-Ramady et al., 2014). Low soil fertility is one of the main factors limiting maize yields and productivity in Western Oromia, Ethiopia (Negassa et al., 2012), relying on inorganic fertilizers to increase crop yields and maintain soil fertility; insufficient fertilizer use leads to serious depletion of soil nutrients (Bisht and Chauhan, 2020; Mafongoya et al., 2006). Over-cultivation and poor soil management in agriculture can lead to soil depletion. The yield potential of maize largely depends on its nutrient management. With the growing understanding of precision agriculture in the context of nutrient management, soil testing is becoming increasingly important (Rowe et al., 2016). In the present and future scenarios, soil testing proves to have a more general role, not limited to recommending fertilizers for crops based on soil testing, but as a measure of maintaining soil quality (Roberts and Johnston, 2015). Phosphorus (P) is the most important nutrient (after nitrogen) limiting agricultural production in most parts of the world (Balemi and Negisho, 2012). Phosphorus is the most yield-limiting element provided by the soil, and soil phosphorus tends to decrease when the soil is used for agriculture) [10,11].

Phosphorus (P) is the most important nutrient element (after nitrogen) limiting agricultural production in most regions of the world. Phosphorous is the most yield limiting of soil-supplied elements, and soil P tends to decline when soils are used for agriculture (Admassu, 2017) [12]. Soil becomes depleted when ingredients that contribute to fertility are not removed and replaced and the conditions that support soil fertility are not maintained. This results in reduced crop yields. Since, spatiotemporal changes in soil fertility are not taken into account, farmers apply the same amount of phosphorus fertilizer in the field regardless of differences in soil fertility (Chikowo et al., 2014). It is generally accepted that economical optimal fertilization can only be achieved through the development of appropriate fertilizer recommendations. However, current site-specific fertilization recommendations for different soil crop climatic conditions are negligible and are absent in the Boneya Boshe district of Western Oromia. As in all other regions of the country, specific fertilizer recommendations for maize in the Boneya Boshe district are important because their application is not based on soil test results) [13]. In Gobu Sayo and Bako districts, soil testing crop response based on phosphorus fertilizer recommendations was completed and verification trials were conducted but not yet completed at Boneya Boshe. Boneya Boshe District is adjacent to these areas and therefore soil test crop response must be extrapolated based on fertilizer results recommended by Bako and Gobu Sayo for Boneya Boshe verification) [14].

Therefore, fertilizer application schedules should be based on the requirement of crop response to applied nutrients at different soil fertility levels (Silveira and Kohmann, 2020). Previously, a maize phosphorus verification study based on soil test crop response was conducted in Gobu Sayo and Bako districts where critical phosphorus values had to be verified to approve acceptance of the technology at farmer level (Tadesse and Mekonnen, 2019). The aim is to verify soil test crop responses based on Pc and Pf recommended by Bako and Gobu Sayo and extrapolated and verified for Boneya Boshe district, Western Oromia) [15].

Materials and Methods

Description of study area

The trial was conducted in Boneya Boshe district, East Wollega Zone in Western Oromia. The area is geographically located 037000.165'E and 09054.097'N. The topography of the area is flat and as well as undulating. The elevation of the area is 1645 m.a.s.l. The annual rain fall 1500 mm classified in mono-modal rain fall distribution, in the months of June to October. The soil of the area is classified as reddish brown (Figure 1).

Experimental design and procedure

The study was conducted in farmers' fields in selected district. The trial had three treatments (control, farmer's practices and phosphorus critical values and Requirement factor), laid out using non-design plots adjacent to each other and replicated on farmers. Based on the results of the previously recommended maize phosphorus critical values and P factors in the Bako and Gobu Sayo regions, it was decided to extrapolate the results to the Boneya Boshe district. Where Pc=Critical P concentration (14.5); Po=Initial P values of the site (ppm); Pf=P-requirement factor 5.5. An improved maize variety (BH-546) was used as the test material, the field area of each treatment was 10 mx10 m (100 m^2), and using a seed rate of 25 25 $kgha^{-1}$. All crop management activities were applied based on farmers practices of the study area. The amount of phosphorus fertilizer applied is according to the formula P (kg P/ha)=(Pc-Po) x Pf. The recommendations were compared with controls and farmers' practices. For verification purposes, the experiment used a randomized complete block design and was replicated among farmers) [16,17].

Datasets and analysis

Composite soil samples were collected at a depth of 0-20 cm from 11 locations in selected farmland prior to planting to determine initial soil available phosphorus (Po). Available soil phosphorus was analyzed by Olsen method (Olsen, 1954). The grain data and biomass yield of the crops were collected. Grain yields were collected from 10 mx10 m (100 m^2) plots to determine significance between treatments. The ratio of

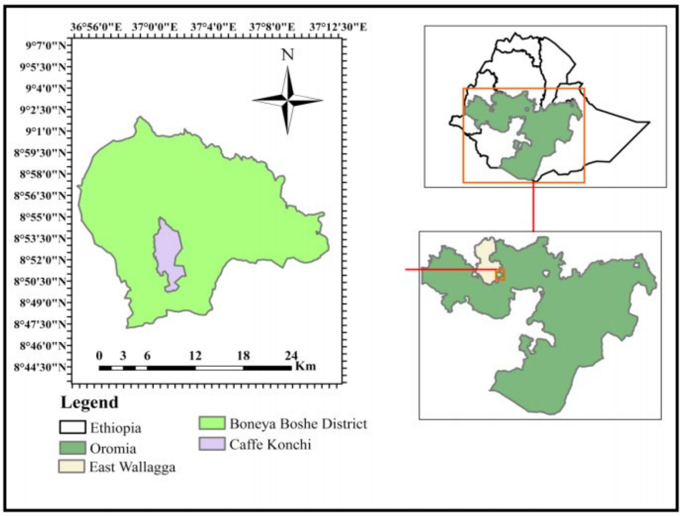

Figure 1: Location map of the study area.

the amount of biomass produced to the amount of substrate consumed (g biomass/g substrate) is defined as the biomass yield and is usually defined relative to the electron donor used (Low and Chase, 1999) [18,19].

Biomass Yield Y=(g biomass produced)/(g substrate utilized)

Harvest Index (HI): It is the ratio of the element content in the grain to the element content in the total above-ground biomass of the plant. The calculation formula is

HI=(Grain Yield)/ (Biomass Yield)

The grain yield and biomass recorded at the plot base were converted into $kgha^{-1}$ for statistical analysis. Finally, analysis of variance was performed on the collected data using Gen-Stat computer software version 18. Mean separation was achieved using least significant difference (LSD) [20].

Hundred seed weight

Hundred-seed weight (HSW) is an important measure of yield and a useful indicator for monitoring the inheritance of quantitative traits that are affected by genotype and environmental conditions (NADEEM and BALOCH, 2023).

Partial budget analysis

Following the (CIMMYT and Cimmyt, 1988), a partial budget analysis was carried out to determine the economic feasibility of the recommended fertilizer P for bread wheat production around the study area, following (CIMMYT, 1998). The average prices of relevant inputs required to carry out part of the budget analysis are collected from different sources. Total variable costs are the costs incurred due to the application of phosphorus fertilizer (both separate from the phosphorus calibration results based on soil testing and the farmer's fertilizer application rate), assuming that all costs incurred by all treatments are the same. Total revenue was calculated by multiplying the average grain yield (kg/ha) of each treatment by the price of one kilogram of grain. Net revenue is calculated by subtracting total variable costs from total revenue. The Marginal rate of return (MRR) for all treatments is calculated using the following formula) [21].

MRR=(Net income from fertilized field – net income from unfertilized field)/(Total variable cost from fertilizer application)

Results and Discussion

Initial soil pH and available phosphorus

Initial soil phosphorus contents ranged from 7.2 to 11 ppm (Table 1), indicating soil phosphorus levels ranging from low to moderate phosphorus (Olsen, 1954). It shows that there are significant differences in soil phosphorus levels in different farmlands in the same district) [22]. The results also showed higher soil pH, ranging from 4.85 to 5.10. The overall pH value of the soil in this area is 5.03, which is highly acidic and requires lime application. Results indicate that strong soil pH and medium phosphorus have high impact on maize yield. Therefore, the soil of the study areas needs application of phosphorus containing fertilizers for crop production.

Grain yield

Analysis of variance showed significant differences between mean grain yields at p<001 (Table 2). Fertilization recommendations based on soil tests recorded the highest average grain yield (6520 $kgha^{-1}$), but the lowest average grain yield was obtained from the control

Table 1: Initial available soil phosphorus and soil pH.

Sites	Soil pH (H_2O)	Available P (ppm)
Site 1	5.12	8.6
Site 2	4.85	7.2
Site 3	5.35	9.6
Site 4	5.1	9.2
Site 5	4.9	7.4
Site 6	5.01	10.1
Site 7	4.86	9.8
Site 8	5.2	11
Site 9	5.1	9.3
Site 10	4.9	10.2
Site11	4.95	9.54
Mean	**5.03**	**9.26**

Table 2: Mean Grain Yield and Biomass Yield, Harvest Index and 100 seed weight of Maize as affected by STBFR in Boneya Boshe District.

Treatments	GRY (kg/ha)	BY (kg/ha)	HI	HSW (g)
T1 (Control)	1515.62^{c}	4312.50^{c}	0.35^{b}	20.69^{b}
T2 (STBFR)	6520.00^{a}	13906.25^{a}	0.47^{a}	27.05^{a}
T3 (F/Practices)	4125.94^{b}	9750.00^{b}	0.42^{ab}	25.47^{a}
LSD (5%)	1002.28	2146.88	0.131	3.234
CV (%)	23.1	21.5	30.1	10.5

STBFR: Soil Test Crop Response Based Fertilizer Recommendation; Means with the same letters are not significantly different.

(1515.62 $kgha^{-1}$). As reported by (Chimdessa et al., 2019; Tadesse and Mekonnen, 2019), fertilizer recommendations based on crop response from soil tests reportedly show higher yields compared to blanket fertilizer recommendation.. The result reveled that soil test crop response based fertilizer recommendation is suitable and economical to obtain optimum yield of maize in the study area through the application of fertilizer that plant requires efficiently. The results of this study are consistent with those of (Tadesse and Mekonnen, 2019), which reported that the highest grain yields were recorded when the recommended soil p-verification was applied) [23].

Biomass yield

Analysis of variance showed that T2 (STBFR) had an extremely significant for aboveground dry biomass yield over locations (P<0.05). T2 (STBFR) obtained the highest biomass yield of (13906.25 $kgha^{-1}$. The control had the lowest biomass yield of 4312.50 $kgha^{-1}$. From this result, it can be seen that aboveground dry biomass yield has a direct positive relationship with the total grain yield of the crop.

Harvest index

Harvest index: is the average of total grain yield divided by total aboveground biomass multiplied by one hundred. It represents the ratio of nutrient transport in biomass to grain yield. Therefore, a statistically highly significant difference of 0.47 was observed for treatment 2 (STBFR) compared to the control treatment, but not statistically significant for the farmer's practice/blanket advice/but a statistically insignificant difference was observed) [24].

Hundred seed weight

Hundred seed weight of treatment two (STBFR) and treatment three (farmer practice) was not statistically significant. However, STBFR was statistically significant compared to the control.

Economic analysis

Marginal rate of returns (MRR) were found to be 2144% for soil

Table 3: Partial budget analysis.

Treatment	Urea	NPS	MGY	TVC(Birr/ha)	GFB	NB(EB/ha)	MRR (%)
	N(kg/ha)	P(kg/ha)	(kg/ha)		(Birr/ha)		
Control	0	0	1515.62	850	22734.3	21884.3	-
F/Practices	100	100	4125.94	3300	61889.1	58589.1	1498
STBFR	200	100	6520	4900	97800	92900	2144

NB: MGY: Mean Grain Yield, TVC: Total Variable Cost, GFB: Gross Field Benefit, NB: Net Benefit, MRR: Marginal Rate of Return

test based P fertilizer rate and 1498% for farmers practices as indicated in Table 3. The economic analysis should that the highest net income (92,900.00 birr) was obtained from soil test based P recommendation with marginal rate of return (2144%) which is greater than the minimum rate of return (MRR) 100% (CIMMIT, 1988). Based on this result, partial budget analysis indicated that soil test based P recommendation is economically feasible for maize production in Boneya Boshe district. To use marginal rate of return (MRR) as the basis for fertilizer recommendations, the minimum acceptable rate of return (MARR) was set to 100%. Partial budget analysis showed that crop response fertilizer recommendations based on soil testing in Boneya Boshe district were acceptable with an MRR of 2144) [24]. According to (Chimdessa and Takele, 2020), a farm economic analysis of major grain reports that an MRR of 50% to 100% is the minimum recommended in most agricultural production and it is better when the MRR was >100%) [25].

Conclusions

Based on the verification of fertilization recommendations, P critical level (14.5) and P requirement factor (5.5) based on soil test crop, the economic analysis showed that the highest net revenue (92,900.00 Birr) was recorded based on marginal soil test crop responses and the return rate is 2144%, which is higher than the minimum acceptable return rate (100%). Therefore, the highest average grain yield (6520 kg/ha) was obtained in STBFR compared to farmer practice and control plots. Therefore, fertilization recommendations based on soil test crop responses are economically feasible for corn production in the district. Thus, the results of Pc and Pf recommendations in the wider area were presented to farmers and subsequently P recommendation techniques were adopted to increase maize yield and productivity in Boneya Boshe district, while further scale-up is expected to promote this technology to farmers in the study area and similar agro-ecologies.

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