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Research Article

Soil Test Crop Response Based Phosphorus Calibration Study for Maize in Negele Arsi District of Western Arsi Zone Oromia

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Abstract

A phosphorus calibration study based on soil testing for maize was carried out in the Negele Arsi district, located in the Western Arsi Zone of Oromia, during the main cropping seasons spanning 2014 to 2016. The primary objectives were to establish the critical phosphorus level (Pc) and determine the phosphorus requirement factor (Pf) for maize, as well as to formulate soil test-based, site-specific phosphorus fertilizer recommendations. The experiment utilized a randomized complete block design (RCBD) with a factorial setup involving five nitrogen application rates (0, 23, 46, 69, and 92 kg ha^{-1}) combined with three doses of phosphorus (0, 46, and 92 kg ha^{-1}) to identify the optimum nitrogen rate for maize cultivation. During the subsequent two years of the study, a fixed nitrogen rate of 69 kg/ha (identified as optimum) was applied across all plots with varying phosphorus levels of 0, 10, 20, 30, and 40 kg ha^{-1} to pinpoint the phosphorus critical value and requirement factor. Soil samples were collected from the composite surface layer at each site before planting and again 21 days post-planting. Results revealed that the highest maize grain yield, averaging 7108 kg/ha, was achieved with an application of 69 kg N/ha alongside 46 kg P_2O_5/ha. The combination of 69 kg N/ha with 69 kg P_2O_5/ha yielded the maximum net return of 209,806 Birr per hectare. The study concluded that the phosphorus critical level for maize production in these soils is 31 ppm, with a phosphorus requirement factor of 3.06. These values merit validation through further trials before recommending for broader application.

Keywords

Phosphorus Calibration, Soil Testing, Maize, Nitrogen Optimization, Soil Sampling

1. Introduction

Maize (Zea mays L.) is a crucial cereal globally, ranking third in importance after wheat and rice [12]. In Ethiopia, it is the second most extensively cultivated food crop by area, trailing only teff [5]. Despite the introduction of improved maize varieties, yields among smallholder farmers have stagnated [15]. Furthermore, agricultural production growth has failed to keep pace with the rising population. Key constraints to productivity include land degradation due to erosion, depletion of soil organic matter through various uses, and imbalanced fertilizer application [1].

Phosphorus deficiency is one of the major limiting factors affecting maize production in Ethiopia, second only to nitro-

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gen deficiency. To sustain maize yield improvements, accurate fertilizer recommendations are necessary. In the Arsi Negele district, farmers commonly use uniform fertilizer rates of 100 kg NPS ha^{-1} and 100 kg urea ha^{-1} for phosphorus and nitrogen, respectively, without considering field-specific soil fertility status. Such blanket fertilizer recommendations are often inefficient and uneconomical because they overlook soil fertility variability among fields [16]. Employing controlled fertilizer application based on soil test-crop response calibration ensures nutrient supply aligns with actual crop needs, reducing under- or over-fertilization. This practice conserves fertilizer resources, minimizes environmental pollution risks from nitrogen and phosphorus runoff, and prevents yield and quality losses [14]. Hence, site-specific fertilizer guidance based on soil testing offers substantial advantages over generalized recommendations.

This method requires understanding the correlation between soil test nutrient levels and crop nutrient requirements to reach optimal yields. Calibration of fertilizer rates must be specific to the crop, soil type, and agro-climatic conditions. Matching fertilizer inputs precisely to crop demand is critical for maximizing agricultural productivity. While maize is the second most widely grown crop in the Negele Arsi district, no site-specific soil test-based fertilizer recommendations are currently available for the area.

Therefore, the objectives of this project include:

1) Determining the phosphorus critical level (Pc) and phosphorus requirement factor (Pf) for maize in Arsi Negele district.
2) Identifying the economically optimum nitrogen fertilizer rate for maize production in the district.
3) Developing guidelines for soil test and crop response-based fertilizer recommendations tailored to representative soils in the district.

2. Materials and Methods

2.1. Description of the Study Area

The study will be conducted in Arsi Negele district, part of the West Arsi Zone, Ethiopia. The district lies at coordinates 38°56´N and 7°23´E, with an average altitude of 2002 meters above sea level. Its rainfall regime is bimodal, featuring a small rainy season (Belg) from March to June and a main rainy season (Meher) from July to November. The district receives an average annual rainfall of 1520 mm, with a mean annual temperature of 19.7℃. The predominant soil type is Andosol with a sandy loam texture. Major crops cultivated include wheat, barley, potato, maize, and teff.

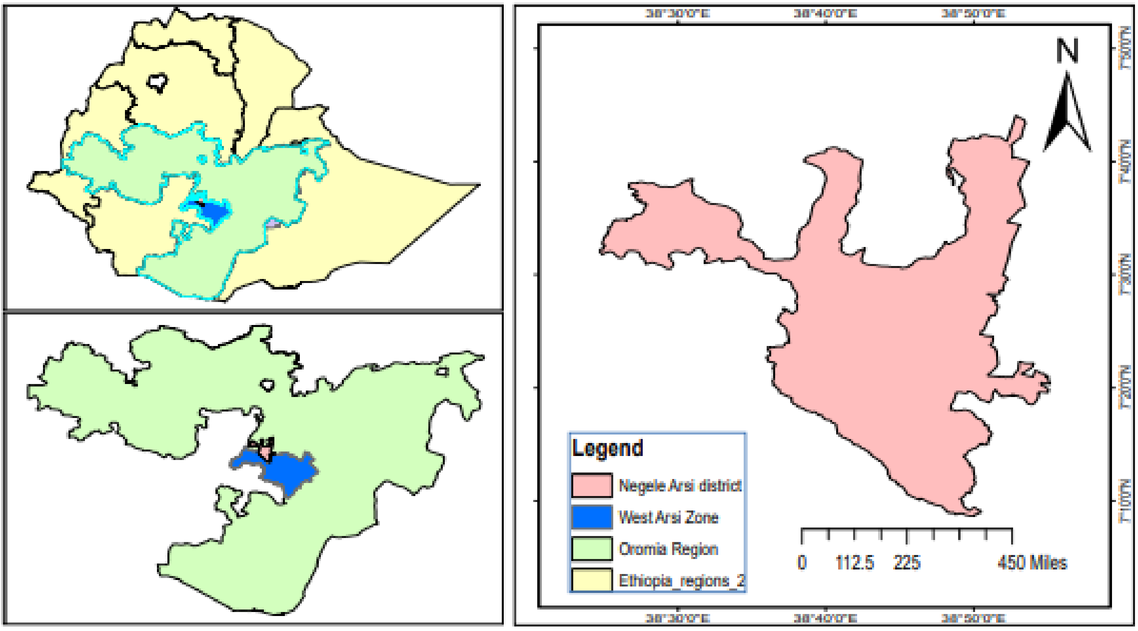

Figure 1. Geographical location of Negele Arsi district.

2.2. Site Selection

For the experiment, maize-growing potential areas within the district were identified in collaboration with the Office of Agriculture and Natural Resources of Arsi Negele district. The study was carried out at seven sites for determining the economically optimum nitrogen rate and at twenty sites for phosphorus critical level determination.

2.3. Experimental Design and Treatments

To establish the economically optimum nitrogen level (applied as urea), five nitrogen rates (0, 23, 46, 69, and 92 kg ha^{-1}) were factorially combined with three phosphorus levels (0, 46, and 92 kg P_2O_5 ha^{-1} from triple superphosphate) in a randomized complete block design (RCBD) with three replications. The economically optimum nitrogen rate was identified through partial budget analysis following [8]. Once the optimum nitrogen rate was established in the first year, it was applied as basal nitrogen to all plots in the subsequent year.

The phosphorus calibration trial was conducted on 20 farmers' fields during the second and third years. The experimental plots measured 4 m by 3 m. Phosphorus treatments included five levels of P_2O_5 (0, 23, 46, 69, and 92 kg ha^{-1}), with the optimum nitrogen rate uniformly applied to all plots. The experiment followed a randomized complete block design with three replications.

Fertilizers were calculated based on nutrient source content, pre-weighed, labeled, and stored in plastic bags before application. Harvesting for grain yield measurements was performed from a net plot area of 3 m by 4 m.

2.4. Soil Sampling and Analysis

Composite soil samples were collected from each farmer's field prior to planting at a depth of 0 to 20 cm using standard soil sampling methods. These samples underwent chemical analysis for soil pH, organic carbon, total nitrogen, available phosphorus, potassium, calcium, magnesium, and cation exchange capacity (CEC). Additional soil samples were taken from each plot 21 days after planting at the same depth for analysis of available phosphorus and pH.

2.5. Data Collection

Agronomic data collected included grain yield and yield components. Economic analysis assessed the profitability of each treatment by adjusting average plot yields to account for differences from farmers' yield levels. Fertilizer prices were based on average open market values in Birr per kilogram. Treatments were considered economically viable if they met Minimum Acceptable Rate of Return (MARR) criteria set at 100% [8].

2.6. Data Management and Analysis

All data gathered across different locations were organized using Microsoft Excel and subjected to analysis of variance (ANOVA) using SAS/STAT version 9.0 or equivalent statistical software.

2.7. Determination of Critical Phosphorus Concentration

The critical soil phosphorus concentration is defined as the threshold below which crops show significant response to phosphorus fertilization, whereas above this level, responses diminish markedly. Critical P values were determined using the Cate-Nelson graphical method by plotting soil phosphorus on the X-axis against relative crop yield on the Y-axis. This method divides the scatter plot into four quadrants and seeks to minimize positive and negative errors by optimally dividing data points.

2.8. Determination of Phosphorus Requirement Factor

The phosphorus requirement factor indicates the kilograms of phosphorus needed to increase the soil phosphorus concentration by 1 ppm. It helps calculate how much phosphorus fertilizer to apply per hectare to raise soil test phosphorus above the critical concentration. This factor was calculated from available phosphorus data collected in both unfertilized and fertilized plots using the formula:

Rate of P fertilizer=(Pc−Pi)×P requirement factor Rate of P fertilizer=$(Pc-Pi)$×P requirement factor

Where Pc is the critical phosphorus concentration and Pi Pi is the initial soil phosphorus level.

3. Result and Discussions

3.1. Characterization of Initial Soil Physicochemical Properties

The average soil pH measured at the study site was 7.22, with available phosphorus (P) content averaging 17.96 ppm as detailed in (Table 1). According to the categorization by [11], the soil pH falls within a normal range while the available phosphorus is classified as medium. Furthermore, soil organic carbon (SOC), total nitrogen (TN), and cation exchange capacity (CEC) were recorded at 1.87%, 0.97%, and 9.23 cmol/kg, respectively (Table 1). Based on the classification criteria provided by the Food and Agriculture Organization (FAO, 2019) and supported by [6], the SOC, TN, and CEC value observed in this region correspond to low fertility categories.

Table 1. Characterization of initial soil physicochemical properties.

Soil parameters	Mean	StD	Mini	Max	Classification	
					Level	References
Soil pH	7.22	0.39	6.70	7.85	Normal	Nachtergael (2023)
avail p (ppm)	17.96	5.56	9.4	27.55	Medium	Nachtergael (2023)
Soil O. C (%)	1.87	0.33	1.37	2.71	Low	FAO,2019
CEC me/100g	9.23	2.11	5.13	14.57	Low	Ayalew et al (2015
Total N(%)	0.17	0.03	0.14	0.25	low	Ayalew et al (2015
Texture	Sandy loam					
Soil type	Mollic Andosol					

3.2. Determination of Optimum Nitrogen Fertilizer

During the initial year, the identification of phosphorus critical levels and phosphorus requirement factor commenced with the determination of the optimal nitrogen fertilizer rate. Partial budget analysis demonstrated that the combination of 69 kg N fertilizer with 69 kg P_2O_5 resulted in the highest net benefit (Table). Therefore, nitrogen rate of 69 kg/ha, equivalent to 150 kg of urea fertilizer, was consistently applied across all treatments during the evaluation of phosphorus critical values and requirement factors.

Table 2. Partial budget (ETB) analysis.

Treatments	N in kg/ha	P_2O_5 in kg/ha	Mean Grain Yield in Kg/ha	Total Variable cost /ha	Gross Income/ha	Net benefit/ha
1	0	0	1279.35	0	38380.5	38380.5
2	23	0	2685.11	2000	80553.3	78553.3
3	46	0	3083.54	4000	92506.2	88506.2
4	69	0	4585.55	6000	137566.5	131566.5
5	92	0	4590.65	8000	137719.5	129719.5
6	0	46	2469.21	3800	74076.3	70276.3
7	23	46	6886.34	5800	206590.2	200790.2
8	46	46	5701.57	7800	171047.1	163247.1
9	69	46	7320.21	9800	219606.3	209806.3
10	92	46	6777.33	11800	203319.9	191519.9
11	0	92	4075.24	7600	122257.2	114657.2
12	23	92	6089.54	9600	182686.2	173086.2
13	46	92	6307.68	11600	189230.4	177630.4
14	69	92	7081.45	13600	212443.5	198843.5
15	92	92	7287.35	15600	218620.5	203020.5

3.3. Response of Maize Grain Yield to N and P Fertilizers Application

Table 3. Interaction and main effect N and P fertilizer on Maize yield.

N kg/ha	P_2O_5 kg/ha		
	0	46	92
0	1279.35^{c}	2469.21^{c}	4075.24^{b}
23	2685.11^{c}	6886.34^{a}	6089.54^{ab}
46	3083.54^{c}	5701.57^{ab}	6307.68^{a}
69	4585.55^{b}	7320.21^{a}	7081.49^{a}
92	4590.65^{b}	6777.33^{a}	7287.35^{a}
CV (%)	19.25		
LSD 0.05	1507.50		

Means within column followed by the same letters are not significantly different at $P \leq 0.05$

Maize grain yield was significantly affected ($P < 0.05$) by both the individual and combined effects of nitrogen and phosphorus fertilization. The highest grain yield, reaching 7,320 kg/ha, was recorded when 69 kg N and 46 kg P_2O_5 per hectare were applied together (Table 3). In contrast, the lowest yield of 1,279 kg/ha occurred in the unfertilized control plots. These findings are consistent with previous research indicating the strong positive influence of nitrogen and phosphorus fertilizers on maize grain production [10, 17]. However, phosphorus alone did not significantly enhance biomass compared to non-fertilized treatments, although biomass increased with higher rates of nitrogen or phosphorus application [2].

3.4. Effect of Phosphorous Fertilizer on Maize Grain Yield and Available Phosphorous

The mean grain yield and available soil phosphorus measured 21 days after planting showed significant variation ($P < 0.05$) across different phosphorus fertilizer levels (Table 4). The highest grain yield recorded was 7,108 kg/ha, resulting from the application of 69 kg P_2O_5 combined with the recommended nitrogen rate of 69 kg/ha. Soil analysis conducted three weeks after planting also indicated that the highest soil available phosphorus content was found in plots receiving 69 kg P_2O_5 along with the recommended nitrogen rate (Table 4).

Several studies across Ethiopia have documented positive effects of phosphorus fertilization on maize yield and its components. For instance, [13] observed significant increases in grain yield, plant height, and thousand-seed weight due to phosphorus application in northwest Ethiopian maize-growing regions. The beneficial role of phosphorus is attributed to its enhancement of root development, strengthening of stalks, and promotion of flowering, fruiting, seed formation, and overall crop maturity [7]. Nonetheless, phosphorus availability to plants is modulated by factors such as soil pH, organic matter content, and microbial activity. A thorough understanding of phosphorus uptake and cycling dynamics in soils is fundamental for optimizing nutrient management and improving maize yields [9].

Table 4. Response of Grain yield and available p to different rates of phosphorous fertilizer.

No.	Treatment combination		Mean Grain yield in Kg/ha	Available P in PPMAfter 21 days
	P_2O_5 in kg/ha	N in kg/ha		
1	0	69	3277^{d}	18.02^{d}
2	23	69	5386^{c}	22.36^{c}
3	46	69	6293^{b}	25.23^{b}
4	69	69	7108^{a}	36.00^{a}
5	92	69	6858^{a}	33.93^{a}
CV (%)			17.44	21.8
LSD(0.05)			352	2.12

Means within column followed by the same letters are not significantly different at $P \leq 0.05$

3.5. Determination of Phosphorus Critical Value (Pc)

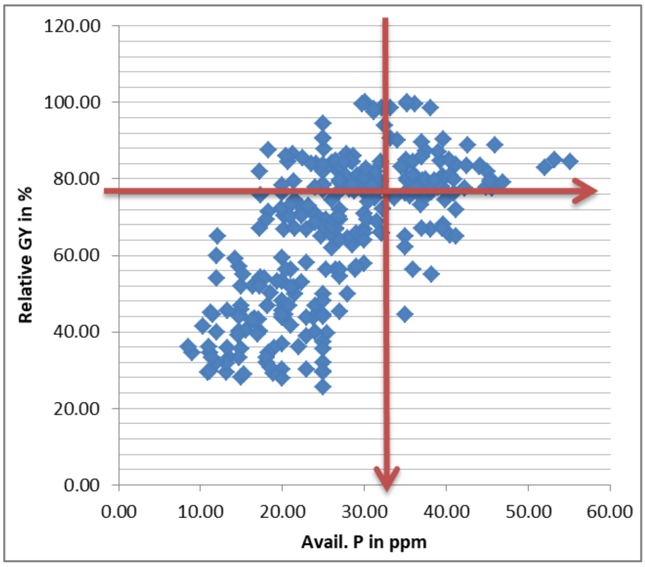

Figure 2. P-critical value for Maize production in Negele Arsi district.

The critical phosphorus concentration (Pc) was identified from a scatter plot comparing maize relative grain yields with corresponding soil phosphorus levels measured through the Olsen method. In this study area, the Cate-Nelson method indicated a critical P concentration of approximately 31 mg P kg^{-1}, which corresponded to an average relative yield of around 75% (Figure 2). Interestingly, the relative grain yield demonstrated a declining trend even when soil test phosphorus values exceeded the critical threshold. Beyond this concentration, increasing phosphorus availability is unlikely to be cost-effective, as the expense of additional fertilizer would probably outweigh the value of any yield gains [3, 4].

3.6. Determination of Phosphorus Requirement Factor (Pf)

The phosphorus requirement factor (Pf) refers to the quantity of phosphorus needed to increase the soil test phosphorus level by 1 mg kg^{-1}. For maize cultivation on Mollic Andosol soils in the Negele Arsi district, the Pf was determined to be 3.06 (Table 5). Therefore, the application rate of phosphorus fertilizer per hectare can be estimated using the soil's critical phosphorus concentration, the initial soil phosphorus values measured at each site prior to planting, and the phosphorus requirement factor (Pf).

Table 5. Phosphorous requirement factor(Pf) for Maize production in Negele Arsi district.

No	Applied P (kg /ha)	Avail. P ppm (Olsen)	Change in avail. P (ppm)	Pf
1	0	17.25	0.00	-
2	10	20.36	3.11	3.22
3	20	23.23	5.98	3.34
4	30	27.34	10.09	2.97
5	40	32.12	14.87	2.69
Average				**3.06**

4. Conclusion and Recommendation

Determining the appropriate balanced chemical fertilizer application is crucial for sustaining enhanced agricultural production and productivity. Hence, conducting accurate soil test-based calibrations is fundamental for the success of fertilizer programs and crop yields. A phosphorus calibration study was carried out for maize grown on Mollic Andosol soils in the Negele Arsi district. The study recommended an economically optimal nitrogen rate of 69 kg N/ha, a phosphorus critical level of 31 ppm, and a phosphorus requirement factor of 3.06 for maize cultivation in the area. However, these findings should be validated prior to demonstration and wider adoption by farmers.

Abbreviations

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CV	Coefficient of Variation
FAO	Food and Agricultural Organization
LSD	Least Significant Different
Pc	Phosphorous Critical Level
Pf	Phosphorous Requirement Factor
Ppm	Perti Per Million

RCBD	Randomized Complete Block Design
SOC	Soil Organic Carbon
TN	Total Nitrogen

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Author Contributions

Kesahun Kitila Hunde: Formal Analysis, Investigation, Writing-original draft, Writing-reviewing& editing

Mekonnen Workineh Lindi: Data curation, Supervision, Writing- original draft, Writing-review& editing

Conflicts of Interest

The authors declare no conflicts of interest.

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