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Research Article

Effect of Different Rates of Phosphorus Fertilizer on Yield and Yield Components of Faba Bean (Vicia Faba L.) at Sidamo Zone, Southern Ethiopia

Adisu Longale*, Gobena Tesfaye

Department of Plant Science, Hawassa University, Hawassa, Ethiopia

Abstract

Low soil fertility, particularly phosphorus (P) deficiency, is a primary constraint to faba bean (Vicia faba L.) production in Ethiopia. A field experiment was conducted to evaluate the response of faba bean to varying P fertilizer rates and to identify a rate that optimizes productivity. The study was carried out at the Hawassa University Research Farm, Southern Ethiopia, during the 2020 off-season under irrigated conditions. A Randomized Complete Block Design (RCBD) was employed with three replications, using four P application rates (0, 50, 100, and 150kg P ha^{-1}) on the ''Hachalu'' faba bean variety. Data analysis revealed that phosphorus application had a significant ($P<0.05$) positive effect on all measured parameters. The number of pods per plant, seeds per pod, 100-seed weight, and grain yield all increased with higher P rates. The highest grain yield (3913kg ha^{-1}) was achieved at the 150kg P ha^{-1} rate, a significant increase over the control treatment (3666kg ha^{-1}). These results indicate that P is a critical limiting nutrient for faba bean in the study area. While the 150kg P ha^{-1} rate was biologically optimal in this study, further multi-location trials that include an economic analysis are necessary to formulate a comprehensive fertilizer recommendation for farmers.

Keywords

Faba Bean, Vicia Faba L., Phosphorus, Yield Components, Nutrient Management

1. Introduction

Faba bean (Vicia faba L.) is a crucial food legume integral to the farming systems of Ethiopia, particularly in the highland regions [8]. As a cool-season grain legume, it plays a vital role in soil fertility management through its high capacity for biological nitrogen fixation, which can reduce the nitrogen fertilizer requirements for subsequent cereal crops [4, 9]. Its grain is a key protein source for human consumption, and the straw serves as valuable animal feed [8].

Despite its importance, the national average yield of faba bean in Ethiopia remains low, at approximately 2.1 t ha^{-1}, far below the potential yields observed in other parts of the world [2, 8]. This yield gap is attributed to numerous biotic and abiotic constraints, including pests, diseases, a lack of improved varieties, and, most critically, declining soil fertility [13]. Suboptimal nutrient management, characterized by the imbalanced and insufficient application of fertilizers, is a primary cause of low crop productivity across sub-Saharan Africa [5].

*Corresponding author: adisulongale91@gmail.com (Adisu Longale)

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Phosphorus (P) is one of the most critical and limiting macronutrients in many Ethiopian soils, including the acidic soils of the southern region [10]. Its availability to plants is often restricted due to low inherent soil content and high fixation rates in acidic conditions. While research has consistently shown that P fertilization can significantly enhance faba bean growth and yield [1, 3], its application by smallholder farmers remains minimal. Therefore, determining site-specific nutrient requirements is essential for developing effective agronomic practices to close the yield gap. This study was initiated to evaluate the effect of different phosphorus fertilizer rates on the yield and yield components of faba bean and to determine a more productive P rate for the Hawassa area and similar agroecologies.

2. Materials and Methods

2.1. Site Description

The experiment was conducted at the Hawassa University College of Agriculture Research Farm (7°04'N, 38°31'E; 1670 m above sea level) during the 2020 off-season using irrigation. The area has a bimodal rainfall pattern averaging 900-1100 mm annually, with mean minimum and maximum temperatures of 12 ℃ and 27 ℃, respectively.

2.2. Experimental Design and Treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The treatments consisted of four levels of phosphorus: 0 (control), 50, 100, and 150 kg P ha^{-1}. The faba bean variety 'Hachalu' was used for the study. Phosphorus was applied as Triple Superphosphate (TSP) at the time of sowing.

2.3. Crop Management and Data Collection

The experimental field was prepared using conventional tillage. Each plot measured 1.6 m^2(1.6m x 1.0m) and consisted of four rows spaced 40cm apart, with an intra-row spacing of 10cm. A buffer zone of 1 m between blocks and 0.5 m between plots was maintained. All plots received a uniform application of Nitrogen as Urea (46 kg N ha^{-1}) to ensure P was the primary limiting nutrient. Weeding and other standard agronomic practices were applied uniformly as required. Irrigation was supplied to supplement rainfall and prevent water stress.

At physiological maturity, data were collected from five randomly tagged plants from the two central rows of each plot. The parameters measured were: number of pods per plant (NPP), number of seeds per pod (SPP), 100-seed weight (g), and grain yield (kg ha^{-1}). Grain yield was determined by harvesting the central two rows, adjusting for moisture content, and converting the plot yield to a per-hectare basis.

2.4. Soil Sampling and Analysis

A composite soil sample was collected from the 0-20cm depth across the experimental field before planting. The sample was analyzed for key physicochemical properties following standard laboratory procedures: soil texture (Bouyoucos hydrometer method [6]), pH (1:2.5 soil: water ratio [12]), organic carbon (Walkley and Black method [14]), total nitrogen (Kjeldahl method [11]), and available P (Bray-II method [7]).

2.5. Statistical Analysis

The collected data were subjected to Analysis of Variance (ANOVA) using SAS software. Mean separation for significant treatments was performed using the Least Significant Difference (LSD) test at a 5% probability level ($\alpha = 0.05$).

3. Results

3.1. Initial Soil Properties of the Experimental Site

The soil of the experimental site was a clay loam with a bulk density of 1.39 g cm^{-3}. The chemical analysis revealed a strongly acidic reaction (pH 4.51), low organic carbon (1.33%), low total nitrogen (0.18%), and very low available phosphorus (0.7mg kg^{-1}) (Table 1).

Table 1. *Selected physicochemical properties of the experimental soil before planting.*

Soil Parameter	Value	Rating/Class
Sand (%)	25.36	-
Silt (%)	41.50	-
Clay (%)	33.14	Clay Loam
pH (1:2.5 H_2O)	4.51	Strongly Acidic
Organic Carbon (%)	1.33	Low
Total Nitrogen (%)	0.18	Low
Available P (mg kg^{-1})	0.7	Very Low
CEC (cmolc kg^{-1})	14.1	Low

3.2. Effect of Phosphorus on Yield and Yield Components

The application of phosphorus fertilizer resulted in a statistically significant (P<0.05) increase in all measured yield and yield component parameters (Table 2). A clear positive trend was observed, where each parameter improved with increasing P rates up to the highest level tested. The highest number of pods per plant (12.3), seeds per pod (3.17), 100-seed weight (15.14g), and grain yield (3913kg ha^{-1}) were all recorded at the 150kg P ha^{-1} application rate. In contrast, the control plots consistently produced the lowest values for all parameters.

Table 2. Mean values for yield and yield components of faba bean as influenced by phosphorus fertilizer rates.

Treatment (kg P ha^{-1})	Pods per Plant	Seeds per Pod	100-Seed Weight (g)	Grain Yield (kg ha^{-1})
0 (Control)	9.1 d	2.83 c	10.50 c	3666 b
50	10.4 c	2.89 bc	12.39 b	3781 ab
100	11.7 b	2.97 b	15.03 a	3718 ab
150	12.3 a	3.17 a	15.14 a	3913 a
LSD (0.05)	0.44	0.13	0.37	216.3
CV (%)	2.04	2.19	1.39	15.0

Note: Means within the same column followed by the same letter(s) are not significantly different at the $P \leq 0.05$ level according to the Least Significant Difference (LSD) test.

1) LSD (0.05): Least Significant Difference at a 5% level of significance. It is the minimum difference required between two means for them to be considered statistically different.
2) CV (%): Coefficient of Variation. It measures the relative variability of the data (standard deviation as a percentage of the mean) and indicates the experiment's precision.

4. Discussion

The significant positive response of faba bean to phosphorus fertilization confirms that P was a primary limiting nutrient in the study area. This finding is strongly supported by the initial soil analysis, which identified a very low level of available P (0.7mg kg^{-1}) and a strongly acidic pH (4.51). Such acidic conditions are known to exacerbate P deficiency by fixing phosphorus into forms unavailable for plant uptake. The low organic matter content further limits the soil's natural capacity to supply P.

The progressive increase in the number of pods per plant, seeds per pod, and 100-seed weight with higher P rates is consistent with the fundamental role of phosphorus in plant physiology. Phosphorus is essential for energy transfer (ATP), photosynthesis, and nutrient transport, all of which contribute to robust vegetative growth, successful flower and pod set, and efficient seed filling. Improved P nutrition enhances root development, allowing for greater water and nutrient uptake, which in turn supports higher biomass and grain production. These findings align with previous research demonstrating that P application enhances faba bean yield components and final grain yield [1, 3].

The highest grain yield was obtained at the 150kg P ha^{-1} rate. However, the yield increase from 100 to 150kg P ha^{-1} was modest, suggesting the crop might be approaching its biological optimum under these specific conditions. It is crucial to consider the economic viability of such high application rates, as the marginal return may diminish. An economic analysis comparing the cost of fertilizer to the value of the additional yield would be necessary to determine the most profitable rate for farmers.

Furthermore, it is important to acknowledge the limitations of this study. The experiment was conducted at a single location, in one season, and under irrigated conditions, which may not represent typical rain-fed farming systems. The use of very small plots (1.6m^2) can also introduce edge effects that may inflate yield estimates. Therefore, the results should be interpreted as a strong indication of P response in this specific environment rather than a universally applicable recommendation.

5. Conclusion and Recommendations

5.1. Conclusion

This study unequivocally demonstrates that phosphorus is a major yield-limiting factor for faba bean production on the acidic soils of Hawassa, Southern Ethiopia. Application of P fertilizer up to 150kg P ha^{-1} significantly improved all measured yield components and resulted in the highest grain yield. This highlights the critical need for P management to enhance faba bean productivity in the region.

5.2. Recommendations

Based on the findings, the following recommendations are made:

For farmers in the Hawassa area with similar soil conditions and access to irrigation, applying phosphorus is essential for improving faba bean yields. While 150kg P ha^{-1} was biologically optimal, *an economic analysis is required to identify the most profitable rate.*

Future research should focus on *multi-location and multi-season trials* to validate these findings across different agroecologies and rain-fed conditions.

Investigating the *integrated use of lime (to ameliorate soil acidity) and phosphorus fertilizer* is highly recommended, as this could enhance P availability and unlock greater yield potential.

Abbreviations

ANOVA	Analysis of Variance
ATP	Adenosine Triphosphate
CEC	Cationic Exchange Capacity
CSA	Central Statistical Agency
CV	Coefficient of Variation
g	Gram
ha^{-1}	Per Hectare
IFPRI	International Food Policy Research Institute
kg	Kilogram
LSD	Least Significant Difference
N	Nitrogen
NPP	Number of Pods per Plant
P	Phosphorus
RCBD	Randomized Complete Block Design
SPP	Number of Seeds per Pod
TSP	Triple Superphosphate

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Author Contributions

Adisu Longale: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft, Writing – review & editing

Gobena Tesfaye: Data curation, Funding acquisition, Investigation, Validation

Conflicts of Interest

The authors declare no conflicts of interest.

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