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Short communication

# THE ROLE OF PHOSPHORUS FERTILIZATION ON GROWTH AND YIELD OF FABA BEAN ON ACIDIC NITISOL OF CENTRAL HIGHLAND OF ETHIOPIA

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**ABSTRACT**: Poor soil fertility and associated low soil pH adversely affect the growth and yield of faba bean (*Vicia faba* L.) on reddish-brown Nitisols of central highlands of Ethiopia. A field experiment was conducted at Holetta Agricultural Research Centre in 2001 and 2002 cropping seasons to study the effect of phosphorus fertilizer on the yield and yield components of faba bean. Five levels of phosphorus fertilizer (0, 13, 26, 39 and 52 kg P $ha^{-1}$) in the form of triple super-phosphate were laid out in randomised complete block design with four replications. Results indicated a positive linear response of faba bean seed yield to phosphorus fertilizer applications. Plant height, number of pods per plant, nodulation score and plant biomass of faba bean were positively ($P \leq 0.01$ and $P \leq 0.001$) influenced by P applications. The application of P fertilizer at the rates of 13, 26, 39 and 52 kg P $ha^{-1}$ also resulted in a linear response with seed yield increment of 24, 31, 38 and 48%, respectively over the control. The results of economic analysis showed that application of 13 kg P $ha^{-1}$ was found to have the highest marginal rate of return for faba bean production.

**Key words/phrases: Acidic soil, faba bean, Nitisol, phosphorus fertilizer, yield**

## INTRODUCTION

Faba bean (*Vicia faba* L.) is among the major grain food legumes cultivated in the highlands of Ethiopia. Currently, faba bean is among the leading pulses, which has attracted great attention in the country due to its demand as an export crop. The yearly average main season area covered by faba bean is about 0.38 million ha making up 36% of the area allotted to pulses (CSA, 2004). However, the productivity of this crop is constrained by low soil pH and associated low P availability (Getachew Agegnehu *et al.*, 2003). In most cases soils with pH values less than 5.5 are deficient in Ca and/or Mg and also P (Soon, 1991). The low yields in acid soils could mainly be either due to the deficiency of nutrients, such as P, Ca and Mg (Somani, 1996), or toxicity of Al, Fe and Mn (Mengel and Kirby, 1996). As a result P deficiency is one of the most widespread soil constraints in these soils.

Phosphorus can readily be rendered unavailable to plant roots as it is the most immobile of the major plant nutrients. Application of P fertilizer to an acid soil resulted in a precipitation reaction between exchangeable $Al^{3+}$ and added P resulting in the formation of a highly insoluble Al-phosphate (Pearson, 1975). In such soils the proportion of P fertilizer that could immediately be available to a crop becomes inadequate and residues of the fertilizer may be released very slowly (Somani, 1996; Getachew Agegnehu and Sommer, 2000). The quantity of P in soil solution needed for optimum growth of crops lies in the range of 0.13 to 1.31 kg P $ha^{-1}$ per day as growing crops absorb about 0.44 kg P $ha^{-1}$ per day (Mengel and Kirby, 1996). The labile fraction in the top soil layer is in the range of 65 to 218 kg P $ha^{-1}$, which could replenish soil solution P (Mengel and Kirby, 1996). The optimum P requirement for faba bean is over 20 ppm.

Legume species differ widely in their ability to grow in soils of low P status. Mahler *et al.* (1988) reported that in terms of nutrient availability pea, lentil, chickpea and faba bean grow best in soils with pH values between 5.7 and 7.2 and require between 13 and 35 kg P $ha^{-1}$ for adequate yields. When pulse crops are grown on soils whose pH values are less than 5.6 they give low yields (Mahler *et al.*, 1988; Schubert *et al.*, 1990). The effect of soil acidity on the productivity of food legumes may be indirect in that soil pH values less than 5.6 are also known to adversely affect *Rhizobium* population (Mahler *et al.*, 1988). Experimental evidences have shown that responses of crops to P and K fertilizers are dependent on the residual fertility level of these nutrients in the soil (Mengel and Kirby, 1996). Schubert *et al.* (1990) reported that at low pH (pH 4.7 and 5.4) dry matter production, seed yield and $N_2$ fixation were significantly lower than at the higher pH levels (pH 6.2 and 7.0).

Phosphorus supply on an Oxisol increased dry matter production of tropical forage legumes by 193%, N concentration in shoot tissue by 10% and percentage of N derived from the atmosphere by 15% (Cadish, 1990). The applications of P increased dry matter production of shoot and root and N concentrations in shoot and root tissue of legumes (Cadish, 1990). Waluyo *et al.* (2004) has also indicated that P and Ca are essential nutrients for root growth, nodule formation and growth of soybean in acid soils. Thus, in order to improve yield, factors that may limit productivity of this crop require closer investigation. The objectives of this study were to find out the effect of P fertilizer on growth, yield and yield components of faba bean and to determine the optimum economic rate of P fertilizer for faba bean production on acid soils (Nitisols) of central Ethiopian highland.

## MATERIALS AND METHOD

The trial site was located at Holetta Agricultural Research Centre between 09°03′N latitude and 38°30′E longitude at an altitude of 2390 m above sea level. The rainfall is bimodal with long-term average annual rainfall of 1100 mm and average minimum and maximum air temperatures of 6 and 22°C, respectively. The environment is seasonally humid and the major soil type of the trial site is Eutric Nitisol.

The experiment was conducted in 2001 and 2002 cropping seasons. The effects of five levels of P fertilizer (0, 13, 26, 39 and 52 kg P $ha^{-1}$) in the form of triple-super-phosphate were studied on growth, yield and yield components of faba bean. The experiment was conducted in a randomised complete block design with four replications. The cultivar used was CS20DK. The P fertilizer was applied at planting. Nitrogen was applied at the rate of 20 kg N $ha^{-1}$ as a starter dressing to all plots in the form of urea. Planting was done in the third week of June at the seed rate of 200 kg $ha^{-1}$ in both seasons on a plot size of 4 m × 5 m. All other cultural practices were followed as per the recommendation. In both seasons faba bean was preceded by wheat.

Soil samples collected before planting from 0–30 cm soil depth were analysed and had a pH (1:1 $H_2O$) of 4.7, 1.29% organic C (Walkley-Black), 0.14% N (Kjeldahl), 5.5 ppm P (Bray-II), 0.05 Na, 1.32 K, 2.75 Ca, 2.12 Mg and a CEC of 20.9 meq100 $g^{-1}$ soil (ammonium acetate pH 7.0 method) (Soil Laboratory, Holetta Research Centre).

Agronomic data such as plant height, nodulation scores (0–4 scale) at 50% flowering, number of pods per plant and seeds per pod, total plant biomass, seed yield, harvest index (HI) and thousand seed weight of faba bean were recorded. Total biomass and seed yield were harvested from 20 $m^2$ and threshed manually. Seed yield was adjusted to 10% moisture content. Analyses of variance were performed using the SAS statistical package program version 8.2 (SAS Institute, 2001). Since data were homogenous the combined mean results of both seasons were reported.

Economic analysis was performed to investigate the economic feasibility of P fertilizer. Partial budget, dominance and marginal analyses were used. The average yield was adjusted downward by 15% to reflect what farmers could get under their own management on large plots of land. Two years (2001–2002) mean market prices for faba bean (ETB 1.55 $kg^{-1}$) and P fertilizer (ETB 2.94 $kg^{-1}$) were used in the analysis. In this study, for a treatment to be considered as a worthwhile option to farmers, the minimum acceptable marginal rate of return (MRR) was considered to be 100% (Amanuel Gorfu *et al.*, 1991).

## RESULTS AND DISCUSSION

### *Yield and yield components*

Crop growing season had a significant ($P \leq 0.01$) influence on seed yield and yield components of faba bean (Table 1). Number of nodules and seeds per pod were not affected by crop season. Seed yield differed significantly due to crop season in that the highest yield of faba bean was obtained in 2001 crop season. This is due to the fact that 2001 was good year for crop growth in terms of moisture status and level of disease infestation. In contrast in 2002 there was a terminal moisture stress during grain filling and maturity season, which resulted in relatively lower yield.

Results indicated that the application of P fertilizer significantly ($P \leq 0.001$ and $P \leq 0.01$) affected seed yield, total plant biomass, thousand seed weight, number of pods per plant and seeds per pod, plant height and number of nodules per plant (Table 1). Phosphorus fertilization also resulted in significant linear responses of total biomass, thousand seed weight, number of pods per plant and seeds per pod, plant height and nodulation of faba bean. The magnitude of response varied with P fertilizer rate. However, harvest index was not significantly affected by the application of P fertilizer (Table 1).

The application of P fertilizer significantly increased yield and yield components of faba bean, while values were decreased by a reduction in rate of application of P. The highest total biomass, seed yield, number of pods per plant and seeds per pod were obtained from the application of 52 kg P $ha^{-1}$. In contrast, the highest thousand seed weight was recorded from the application of 26 kg P $ha^{-1}$. However, there was no statistically significant difference among the rates of 26, 39 & 52 kg P $ha^{-1}$ for thousand seed weight. Faba bean seed yield increment was consistent with P application rates. The application of P fertilizer at the rates of 13, 26, 39 and 52 kg P $ha^{-1}$ significantly and linearly increased mean seed yield with yield advantages of 24, 31, 38 and 48%, respectively compared to the control. The regression line also showed that mean seed yield of faba was most strongly correlated with P rate (Fig. 1). Likewise the findings of Amare Ghizaw *et al.* (1999) and Getachew Agegnehu *et al.* (2003) showed that faba bean seed yield, total biomass, number of pods per plant and plant height increased with increasing rates of P application.

**Table 1. Seed yield and total biomass (kg $ha^{-1}$), harvest index, thousand seed weight, number of pods per plant and seeds per pod of faba bean as influenced by P fertilizer at Holetta, 2001–2002.**

| Factor | Seed Yield | Total biomass | Harvest index | 1000-seed weight | Pods per plant | Seeds per pod | Plant height | Nodule[1] number |
|---|---|---|---|---|---|---|---|---|
| Year | | | | | | | | |
| 2001 | 1878 | 4423 | 0.43 | 523 | 10.1 | 2.6 | 133 | 2.7 |
| 2002 | 1559 | 3396 | 0.46 | 515 | 7.4 | 2.5 | 124 | 2.8 |
| F-probability | *** | *** | ** | * | *** | NS | ** | NS |
| *SE* | 36.4 | 81.2 | 0.01 | 2.5 | 0.23 | 0.04 | 1.2 | 0.08 |
| P (kg $ha^{-1}$) | | | | | | | | |
| 0 | 1338 | 3124 | 0.43 | 493 | 7.3 | 2.4 | 121 | 2.3 |
| 13 | 1667 | 3852 | 0.43 | 508 | 8.2 | 2.5 | 126 | 2.7 |
| 26 | 1759 | 3982 | 0.44 | 534 | 8.7 | 2.6 | 130 | 2.9 |
| 39 | 1850 | 4145 | 0.45 | 528 | 9.4 | 2.7 | 131 | 3.0 |
| 52 | 1974 | 4446 | 0.45 | 529 | 10.2 | 2.7 | 134 | 3.0 |
| F-probability | *** | *** | NS | ** | ** | * | *** | ** |
| Linear | *** | *** | NS | *** | *** | ** | *** | ** |
| *SE* | 57.56 | 128.45 | 0.01 | 3.93 | 0.36 | 0.06 | 1.94 | 0.18 |
| *CV* (%) | 16.41 | 16.1 | 9.21 | 3.71 | 20.1 | 11.7 | 7.41 | 22.31 |

*, **, ***Significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ probability levels, respectively; NS = Not significant. [1]Number of nodules (0 - 4 scale), where 0 = no nodule per plant, 1 = 1-5 nodules, 2 = 6-15 nodules, 3 = 16-30 nodules and 4 = more than 30 nodules per plant.

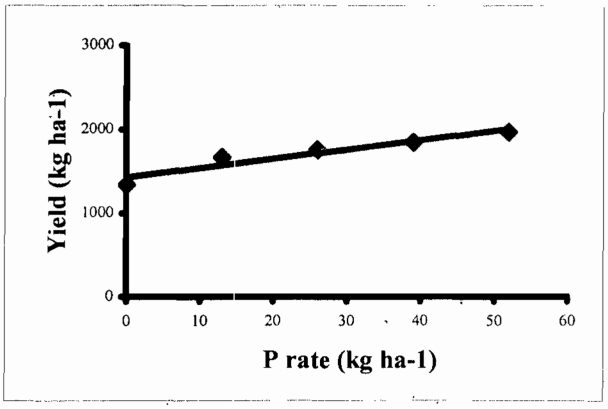


**Fig. 1. The relationship between faba bean grain yield and P rate.** (Seed yield (kg $ha^{-1}$) = 11.19P + 1426.6; $r^2$ =0.91).

Faba bean nodule numbers recorded on plants fertilized with P were also greater over unfertilized ones. The response of faba bean nodulation increased significantly as the rate of P increased. Maximum nodule number was scored from the application of 39 kg P $ha^{-1}$. Tekalign Mamo and Asgelil Dibabe (1994) also showed that a high number of nodules per plant were scored when faba bean was fertilized with P/K fertilizers on Nitisols. Similarly, Israel (1987) indicated that P has specific roles in nodule initiation, growth and functioning in addition to its effects on host plant growth process. Cadish (1990) also indicated that the effect of P deficiency on $N_2$ fixation was associated with reduced nodule mass in which severe P deficiency quickly led to a strong reduction in nodule weight. The application of P fertilizer on an Oxisol at the rate of 75 kg P $ha^{-1}$ resulted in 259% more $N_2$ being fixed by different tropical forage legumes than at 5 kg P $ha^{-1}$ (Cadish, 1990).

*Economic analysis*

According to the results of partial budget analysis, the highest net benefit (ETB 2005.17 $ha^{-1}$) was obtained from the application of 13 kg P $ha^{-1}$ (Table 2). The net benefit increased for the increment in the total variable cost only up to 13 kg P $ha^{-1}$, which sharply decreased after this treatment. The cost-benefit curve also depicts this fact (Fig. 2). The net benefit (ETB 1762.82) obtained from the control treatment was the lowest. The results of dominance analysis show that treatments other than 0 and 13 kg P $ha^{-1}$ are dominated. Since no beneficiary will prefer alternatives that give lower net benefits than net benefit of the alternative with lower total variable costs, the dominated treatments were eliminated from further economic analysis.

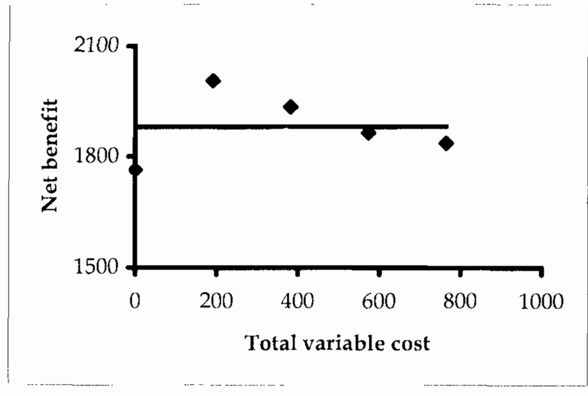


**Fig. 2. Cost benefit curve for P fertilizer rate.** (Net benefit (ETB $ha^{-1}$) = 0.0026C + 1879.6, $r^2$ = 7E-05.)

The marginal rate of return for the non-dominated treatments was found to be 127% (Table 2). This implies that for each ETB 1.00 investment in faba bean production, the producer can get ETB 1.00 and additional ETB 1.27. Since the minimum acceptable rate of return assumed in this experiment was 100%, the treatment with application of 13 kg P $ha^{-1}$ gave an acceptable marginal rate of return. Therefore, according to the results of the economic analysis, faba bean producers on Nitisols of the central highlands of Ethiopia could get the highest marginal rate of return with the application of 13 kg P $ha^{-1}$.

**Table 2. Partial budget analysis for phosphorus fertilizer experiment on faba bean at Holetta Research Centre, 2001-2002.**

| P rate (kg ha$^{-1}$) | Yield (kg ha$^{-1}$) | Adjusted yield -15% (kg ha$^{-1}$) | Gross benefit (ETB ha$^{-1}$) | Fertilizer cost (ETB ha$^{-1}$) | TVC[1] (ETB ha$^{-1}$) | Net be nefit (ETB ha$^{-1}$) | Dominance | MC (ETB ha$^{-1}$) | MNB (ETB ha$^{-1}$) | MRR (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1338 | 1137.30 | 1762.82 | 0 | 0 | 1762.82 | | | | |
| 13 | 1667 | 1416.95 | 2196.27 | 191.10 | 191.10 | 2005.17 | - | 191.10 | 242.35 | 126.82 |
| 26 | 1759 | 1495.15 | 2317.48 | 382.20 | 382.20 | 1935.28 | Dominated | - | - | - |
| 39 | 1850 | 1572.50 | 2437.38 | 573.30 | 573.30 | 1864.08 | Dominated | - | - | - |
| 52 | 1974 | 1677.90 | 2600.75 | 764.40 | 764.40 | 1836.35 | Dominated | - | - | - |

[1]TVC = Total variable cost; MC = Marginal cost; MNB = Marginal net benefit; MRR = marginal rate of return.

In conclusion, despite yield increment due to increased rate of P fertilizer, the economic yield was obtained from the lowest P rate (13 kg P ha$^{-1}$). The analytical results of the soil were found to be sub-optimal for the production of faba bean. The lower response to P could mainly be due to P fixation, which in most cases is the result of soil acidity. Therefore, it is suggested that further studies involving lime and other soil fertility ameliorating inputs should be carried out for efficient and economical use of applied P fertilizer in faba bean production.

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