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Optimization of P and K fertilizer recommendation for faba bean in Ethiopia: the case for Sekela District

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ABSTRACT

Ethiopian soils are recently reported to exhibit multi-nutrient deficiency. Legume crops can satisfy their nitrogen (N) demand through biological N fixation. However, other nutrients should be supplied in optimal amount in the form of fertilizers. Thus, this study was conducted to evaluate the response of faba bean to different levels of phosphorus (P) and potassium (K) fertilizers. The study was conducted in Sekela district of West Gojam Zone of Amhara region from 2014 to 2015. Four levels of K (0, 12, 24 and 36 K_2O kg ha^{-1}) and five levels of P (0, 23, 46, 69 and 92 kg P_2O_5 ha^{-1}) in the first year and four levels of P (0, 23, 46 and 69 kg P_2O_5 ha^{-1}) in the second and third years were combined in incomplete factorial arrangement with a satellite treatment comprising S, Zn, Mg and B. Except the control treatment (non-fertilized), all the rest treatments were inoculated with FB-4 in the first year and EAL-110 rhizobia bacteria in the second and third experimental years. The treatments were laid in a randomized complete block design with three replications. P, K, S and Mg fertilizers were applied as basal application, while, the micronutrients Zn and B were applied as foliar application 45 days after planting. Significant ($P \leq 0.05$) yield response to the addition of P and K fertilizers was recorded in two experimental years. In the first experimental year, the highest grain of 3.2 t ha^{-1} was obtained from application of 92/24 P_2O_5/K_2O kg ha^{-1} statistically at par with 46/0 P_2O_5/K_2O kg ha^{-1}. While, in the second experimental year, the maximum grain yield of 4.3 t ha^{-1} was obtained from application of 46/0 P_2O_5/K_2O kg ha^{-1}. The partial budget analysis result showed that the maximum marginal rates of return of 611 and 463.5% and maximum net economic returns of 1768.1$ and 2975.2$ were obtained from application of 46 kg P_2O_5 ha^{-1} in the first and second experimental years, respectively. Thus, the combined use of the rhizobia strains FB-4 and EAL-110 with 46 kg P_2O_5 ha^{-1} is recommended to improve productivity and economic return of faba bean production in Sekela district and similar agro-ecologies.

***Keywords*:** faba bean, fertilizer, phosphorus, rhizobia inoculation, *Vicia faba*, Sekela

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1. INTRODUCTION

Ethiopia is one of the largest faba bean producing countries in the world only second to China. The country is considered as the secondary center of diversity and also one of the nine major agro-geographical production regions of faba bean. Faba bean is grown as field crop throughout the highlands and is most common between the altitudes of 1800 and 2400 metres above sea level (masl) in Ethiopia. Occupying about 39.31% of the area coverage of individual grain legumes, faba bean is one of the major food legumes grown and it serves as an important source of protein in the diet of most of the population in the country. However, the national average productivity of faba bean in the country is limited to 20.5 t ha^{-1}.

Endalkachew reported soil N deficiency to be common in the tropics and subtropics. Thus, N supply and N management will continue to be significant factors in crop production in the region. Inoculation of faba bean cultivars was significant for total biological yield, seed yield and total nitrogen. Therefore, symbiotically effective rhizobia increase nodulation, N-fixation, growth and yields of their host plant.

Nitrogen and phosphorus were considered as the only major nutrients that largely limit plant growth in smallholder farms in Africa. However, nutrient mining due to sub optimal fertilizer use in one hand and unbalanced fertilizer uses on the other have favored the emergence of multi nutrient deficiency in Ethiopian soils that in part may contributed to fertilizer factor productivity decline experienced over recent past. Different research reports indicate that nutrients like K, S, Ca, Mg and all micro-nutrients except Fe are becoming depleted and deficiency symptoms are being observed on major crops in different areas of the country.

Recently acquired detail soil survey data from EthioSIS (Ethiopian Soil Information System) revealed that in addition to nitrogen and phosphorus, K is reported to be deficient in most of the cultivated land in the country. Legume crops including faba bean can satisfy their N demand through biological N fixation if there is effective indigenous rhizobia strain or artificially inoculated with effective rhizbium. However, P and K nutrients should be supplied optimal in the form of fertilizer to meet the crop demand. This research was therefore initiated with the objective of optimizing P and K fertilizer recommendations for faba bean.

2. MATERIALS AND METHODS

2. 1. Experimental Site Description

Table 1. Some physico-chemical characteristics of surface soil of the study district.

Soil property	Value
pH (H_2O)	5.57
Organic carbon (%)	1.10
Cation exchange capacity (meq 100 gm^{-1})	24.28
Texture	Clay

This study was conducted in Sekela district of West Gojam Zone of Amhara region in Ethiopia for two years (2014-2015). The study district is located at coordinates of 11°10′N latitude and 37°00′E longitude. It receives a mean annual rainfall of 1804.9 mm with mean minimum and maximum temperatures of 8.2 and 23.4 ºC, respectively. Some physico-chemical characteristics of the study district is given in the table below (Table 1).

2. 2. Experimental Procedures and Treatments

The field was ploughed and prepared with an oxen-drawn traditional tool called *Maresha*. The experimental field was then divided in to experimental plots which had an area of 4 m × 3 m. The space between each plot and block was 1 m. An improved variety of faba bean *Wolki* was planted in a row with 40 cm and 10 cm spacings between rows and plants, respectively. Faba bean seeds were moistened with water and inoculated with the strain under a shade immediately before planting. Composite surface (0-20 cm) soil samples were collected at planting for the determination of pH, texture, OC, TN and available P analysis.

Five levels of phosphorus (0, 23, 46, 69 and 92 P_2O_5 kg ha^{-1}) and four levels of K (0, 12, 24 and 36 K_2O kg ha^{-1}) in the first year and four levels of phosphorus (0, 23, 46 and 69 P_2O_5 kg ha^{-1}) and four levels of K (0, 12, 24 and 36 K_2O kg ha^{-1}) in the second experimental year were combined in incomplete factorial arrangement. There was an additional diagnostic satellite treatment comprised of extra macro and micronutrients such as S, Mg, Zn and B (23N, 46P_2O_5, 24K_2O, 5S 5Mg, 1Zn and 0.5B) in all experimental years. Except the control treatment (non-fertilized), all the rest treatments were inoculated with FB-4 and EAL-110 in the first year and second experimental years, respectively. The treatments were laid in randomized complete block design with three replications.

Phosphorus, K, S and Mg fertilizers were all applied as basal application in the form of triple superphosphate (TSP), muriate of potash (KCl), $CaSO_4$ and MgO, respectively. While, Zn and B were applied as foliar application 45 days after planting in the form of $ZnSO_4$ and Borax, respectively.

2. 3. Data Collection and Analysis

The inner rows excluding the boarder were harvested at maturity and yield and yield related parameters were measured. The grain yield measured was adjusted to 14% moisture content. Composite surface soil (0-20 cm) samples were collected from each site at planting for the determination of pH, organic carbon, total N, cation exchange capacity (CEC) and texture. The agronomic data collected were subjected to analysis of variance (ANOVA) using SAS statistical software version 9.0, and mean separation was done using Duncan's Multiple Ranges Test (DMRT) method at 5% level of significance. The partial budget analysis was done following the CIMMYT procedure.

3. RESULTS AND DISCUSSION

First Year I (2014)

Yield and Yield Components

The first year result indicated that there was a significant yield response to the application of P and K fertilizers. The highest grain yield of 3.2 t ha^{-1} was obtained from application of

92/24 P_2O_5/K_2O kg ha^{-1} fertilizers followed with insignificant difference by the grain yield (2.6 t ha^{-1}) obtained from application of 46 kg P_2O_5 ha^{-1} without K (Table 2).

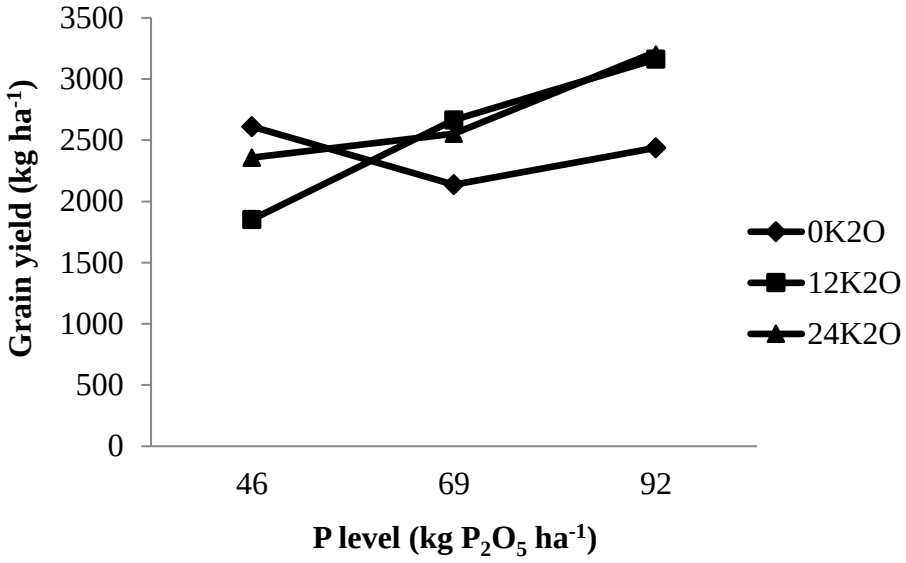
Table 2. Effect of application of P and K fertilizer on the yield of inoculated faba bean in 2014

Treatment*	Plant height (cm)	No of pod per plant	100 seed wt. (g)	Grain yield (kg ha^{-1})
1. Control	93	12.8	52.6	1465.0
2. Inoculant alone	102	10.1	59.4	1955.9
3. 23/0 P_2O_5/K_2O	116	15.7	60.7	2361.6
4. 46/0 P_2O_5/K_2O	113	18.3	59.9	2611.9
5. 69/0 P_2O_5/K_2O	121	18.7	56.7	2136.9
6. 92/0 P_2O_5/K_2O	115	18.3	54.8	2437.4
7. 46/12 P_2O_5/K_2O	109	15.7	57.5	1852.6
8. 69/12 P_2O_5/K_2O	122	18.5	59.5	2665.6
9. 92/12 P_2O_5 /K_2O	128	18.1	61.9	3161.7
10. 46/24 P_2O_5/K_2O	122	16.9	56.9	2358.4
11. 69/24 P_2O_5/K_2O	117	15.3	59.2	2553.7
12. 92/24 P_2O_5/K_2O	126	15.1	62.3	3222.2
13. 46/36 P_2O_5/K_2O	119	16.8	60.3	2881.6
14. 69/36 P_2O_5/K_2O	120	17.2	62.1	2432.3
15. 92/36 P_2O_5/K_2O	124	15.8	62.9	2552.7
16. Diagnostic: 23N, 46P_2O_5, 24K_2O, 5S, 5Mg, 1Zn, 0.5B	103	17.2	51.5	1806.3
GM	116	16.3	58.6	2403.5
CV (%)	12.4	24.4	9.0	22.6
LSD (5%)	NS	NS	NS	905.9

*****All the treatments except the control treatment were inoculated with rhizobia strain FB-4. Means without a letter or followed by the same letter within a column are not statistically significantly ($p \geq 0.05$) different.

The yield response curve to the addition of P fertilizer at different levels of K fertilizer showed that there was an increasing and predictable trend of yield response to the addition of

P fertilizer with 12 and 24 kg ha^{-1} K_2O levels (Graph 1). While, at 0 kg ha^{-1} K_2O level, there was no predictable trend of yield response to the application of P (Graph 1).



Graph 1. Grain yield response curve to P fertilizer at 0, 12 and 24 kg K_2O ha^{-1}

Partial Budget Analysis

The partial budget analysis result of the variable cost data collected in the first experimental year shows that the maximum marginal rate of return (MRR) of 668% was obtained from application of 23 kg P_2O_5 ha^{-1} followed by a MRR of 611% from application of 46 kg P_2O_5 ha^{-1} (Table 3). However, the maximum net economic return of 1768.1$ was obtained from application of 46 kg P_2O_5 ha^{-1}.

Table 3. Partial budget analysis for the use of P fertilizer on faba bean in 2014

P_2O_5 (kg ha^{-1})	Yield (kg ha^{-1})	Unit Yield cost/kg	Total revenue	Fertilizer cost	Labor cost	Total prod cost	Net Return	Marginal product	Marginal cost	MRR (%)
0	1956	0.70	1377.7	0	0	0	1377.6			-
23	2362	0.70	1663.4	28.8	13.9	42.7	1620.6	285.7	42.7	668
46	2612	0.70	1839.7	57.7	13.9	71.6	1768.1	176.3	28.8	611
69	2137	0.70	1505.1	86.5	17.4	103.9	1401.2	-334.6	32.3	-1035

Note: All costs are expressed in the United States dollar currency ($).

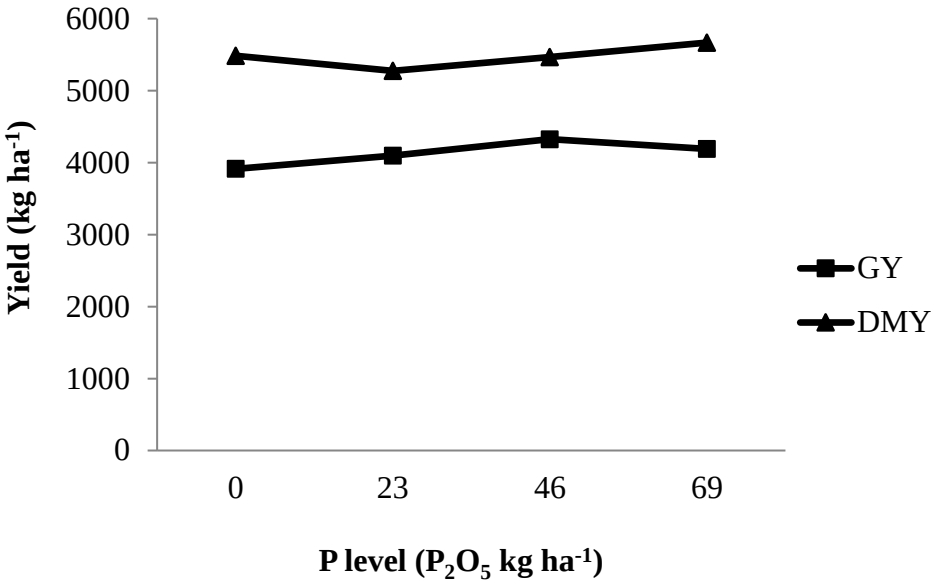
Second Year (2015)

The second year data analysis result indicated that there was a significant effect of treatments on the yield and yield traits of faba bean (Table 4). The maximum grain yield of 4.3 t ha^{-1} was obtained from application of 46 kg P_2O_5 ha^{-1} with the rhizobia strain EAL-110. While, the lowest grain yield of 3.4 t ha^{-1} was measured from the control treatment. A grain yield advantage of 26% over the control treatment was found by the combined use of the rhizbia strain EAL-110 with 46 kg P_2O_5 ha^{-1}. Though the maximum dry matter yield was recorded from the use of 46/12 P_2O_5/K_2O, a statistically similar yield was also measured from the use of 46 kg P_2O_5 ha^{-1}.

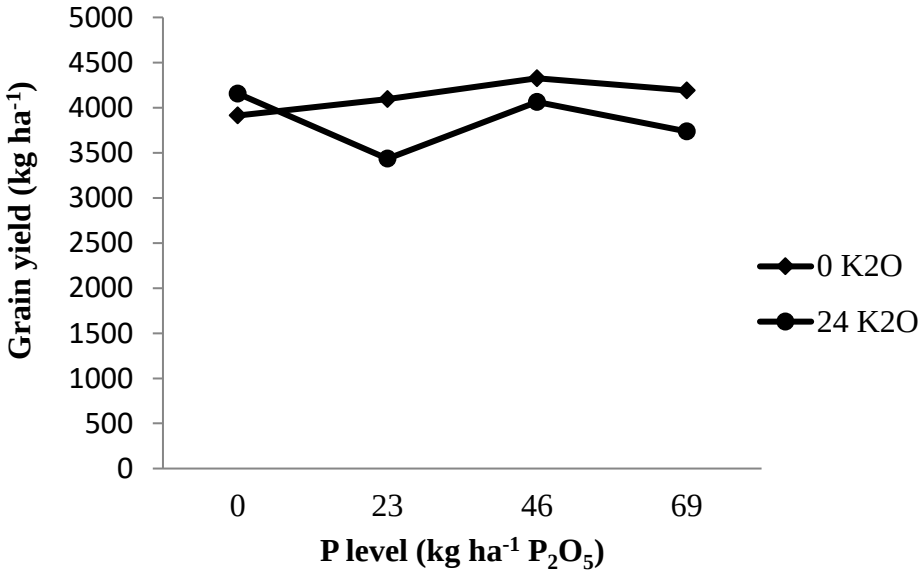
Table 4. Effect of P and K fertilizer application on the yield and yield traits of faba bean in 2015

Treatment*	Plant height (cm)	No of pod per plant	No of seed per pod	100 seed wt. (g)	Grain yield (kg ha^{-1})	Dry matter yield (kg ha^{-1})
1. Control	124.6	17.2b	2.9	57.0	3433.0c	4607.4d
2. Inoculant (FB-4)	129.6	18.0b	3.1	60.3	3912.6ab	5484.0abc
3. 23/0 P_2O_5/K_2O	131.7	17.9b	2.8	60.7	4095.0ab	5274.1abc
4. 46/0 P_2O_5/K_2O	134.0	17.5b	3.3	59.7	4325.6a	5466.7abc
5. 69/0 P_2O_5/K_2O	136.5	18.7b	3.3	61.0	4192.1ab	5666.7ab
6. 0/24 P_2O_5/K_2O	129.3	16.7b	3.1	57.3	4156.1ab	5651.9.0ab
7. 23/24 P_2O_5/K_2O	125.0	15.9b	3.2	59.3	3433.9c	4533.3d
8. 46/24 P_2O_5/K_2O	132.7	20.0b	3.1	59.7	4063.2ab	5284.0abc
9. 69/24 P_2O_5/K_2O	140.8	23.7a	3.3	59.3	3737.5bc	5466.7abc
10. 46/12 P_2O_5/K_2O	133.7	19.4b	3.1	60.7	4295.3a	5792.6a
11. 46/24/5/5/1/0.5 P_2O_5/K_2O/S/Mg/Zn/B	133.1	18.1b	2.8	58.7	3727.5bc	4960.5cd
12. 46/36 P_2O_5/K_2O	127.5	16.7b	3.5	56.3	4157.4ab	5200.0bc
GM	131.5	18.3	3.1	59.2	3960.8	5282.3
CV (%)	6.1	11.8	9.3	4.6	6.4	5.2
SED	8.06	2.16	0.29	2.73	254.87	276.72

*****All the treatments except the control treatment were inoculated with rhizobia strain EAL-110. Means without a letter or followed by the same letter within a column are not statistically significantly ($p \geq 0.05$) different.



Graph 2. Yield response of faba bean to application of P fertilizer at 0 kg ha^{-1} K_2O



Graph 3. Yield response of faba bean to application of P fertilizer at different levels of K_2O (kg ha^{-1})

Partial Budget Analysis

The partial budget analysis of the second year grain yield data, as shown in the table below, indicated that the maximum MRR 454% of was found from application of 20P kg ha^{-1} followed by MRR of 304% obtained from application of 30P kg ha^{-1} (Table 5). The maximum

net economic return was also found from application of 20P kg ha^{-1} exceeded by the net economic return calculated for application of 30P kg ha^{-1} with very small difference.

Table 5. Partial budget analysis for the use of P fertilizer on faba bean yield in 2015

P_2O_5 (kg ha^{-1})	Yield	Unit Yield cost/kg	Total revenue	Fertilizer cost	Labor cost	Total Prod cost	Net Return	Marginal product	Marginal Cost	MRR (%)
0	3912	0.7	2755.8	0.0	0.0	0.0	2755.8			
23	4095	0.7	2884.3	28.8	13.9	42.7	2841.6	85.7	42.7	200.6
46	4325	0.7	3046.7	57.7	13.9	71.6	2975.2	133.6	28.8	463.5
69	4192	0.7	2952.7	86.5	17.4	103.9	2848.8	-126.3	32.3	-391.1

Note: All costs are expressed in the United States dollar currency ($).

4. CONCLUSIONS

The result obtained in this study revealed that there was a significant yield response to the application of P fertilizer in the two experimental years. The highest yield with maximum net economic return was obtained from application of 46 kg ha^{-1} P_2O_5 fertilizer. Thus, the combined use of the rhizobia strains FB-4 and EAL-110 with 46 kg P_2O_5 ha^{-1} is recommended to improve productivity and economic return of faba bean production in Sekela district and similar agro-ecologies.

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