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EFFECTS OF COMBINED APPLICATION OF PHOSPHORUS AND SULFUR FERTILIZERS ON AGRONOMIC TRAITS AND PROTEIN CONTENT OF SUPPLEMENTARY IRRIGATED HARICOT BEAN (*PHASEOLUS VULGARIS*) VARIETIES IN RAYA VALLEY, NORTHERN ETHIOPIA

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ABSTRACT

Haricot bean is primarily grown in Ethiopia for human consumption and export earnings. A market demand for haricot bean, both in the domestic and export market, has triggered the production of haricot bean in selected areas of Ethiopia though its production is constrained by several factors such as poor soil fertility and erratic rainfall. This study was carried out to investigate the combined effect of phosphorus and sulfur fertilizers on yield, yield related traits and protein content of haricot bean (Phaseolus vulgaris) varieties at the research field of Mekoni Agricultural Research Center during 2016/17 cropping season. The experiment was laid out in split plot design where varieties were assigned to the main plots and fertilizer rates to the sub plots in three replications. Three phosphorus (P) rates (10, 20 and 30 kg ha^{-1}) were combined with four sulfur (S) rates (15, 30, 45 and 60 kg ha^{-1}) and applied in combination to Melka Awash-98 and Nasir varieties. Data on phenological, agronomic and quality traits were collected and determined. Partial budget analysis was carried out to assess the profitability of the applications. P-S fertilizer treatments were significantly affected by varieties. Treatments were significantly affected by varieties and the imposed P and S rates. The interaction effect due to variety by fertilizer the two factors significantly affect days to flowering, plant height, hundred seed weight and protein content. Tallest plants, fewer days to flowering and maturity, many pods/plant, heavier seeds, higher grain yield ha^{-1} and better protein content were recorded where the fertilizer application rate was 20 kg ha^{-1}P and 30 kg ha^{-1} S for both varieties. Grain yield ranged from 1520 to 3000 kg ha^{-1} depending on P-S fertilizer rates and varieties. Nasir variety seems to be superior over Melka Awash-98 for most traits except protein content. However, production of Melka Awash-98 under 20 kg ha^{-1}P and 15 kg ha^{-1} S fertilization tend to be more economical as it resulted in highest net benefit return. Although not profitable, planting Melka Awash-98 using an application rate of 20 kg ha^{-1}P and 30 kg ha^{-1} S could be suggested for use in the area to ensure earliness and high grain yield.

Key words: Haricot bean, fertilizer, phosphorus, sulfur, irrigation, yield, protein, net benefit

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INTRODUCTION

Ethiopia is known as the homeland for several domesticated crop plants. It is among the top pulse producing countries in the world. Out of total Ethiopian grain production, pulses accounts 11%, second most important element in the national diet, being the principal source of protein and crucial dietary supplement to cereal consumption [1, 2]. Pulses are important mainly for making "wot", an Ethiopian stew, which is sometimes served as a main dish. Pulse has also been used for several years in crop rotation practices. Haricot Beans are one of the most important varieties of pulses grown in Ethiopia [3]. According to the Central Statistical Agency [4], haricot bean is grown on an estimated 323,327 ha by nearly 3.2 million smallholder farmers and its production reaches 513,724 t with an average of 1.6 t ha^{-1}. In Tigray region, about 1.1 million ha of arable land is devoted to haricot bean production with total production of 7.8 million t and productivity of 0.74t ha^{-1} [4]. The area coverage of haricot bean production has been growing gradually in Ethiopia due to its dietary importance and cash earnings [5, 6, 7]. In spite of these values, the research on this commodity is lagging behind and the knowledge of agronomic packages and production constraints is missing.

The low productivity and production of haricot bean could be attributed mainly to existing low yielding varieties, low soil fertility, unbalanced use of external soil inputs, unpredictable and erratic nature of the rainfall. Some studies on soils tested for nitrogen (N), phosphorus (P), potassium (K), sulfur (S) and micronutrients levels indicate that there is deficiency of these nutrients in Tigray [8]. Moreover, total N, P and K inputs to small holder fields do not balance nutrient removal in the form of crop yield and animal feeds in northern Ethiopia [9]. Consequently, the soil nutrient stocks in the soil are declining at high rates. This deficiency has been limiting the productivity of many crops including haricot bean. The low productivity of haricot bean is related to low soil phosphorus content [10]. According to the report by ATA and MoA [11], S and P were identified as a deficient nutrient in Raya valley in northern Ethiopia. However, P and S fertilizer rate calibration against the yield responses of major crops is lacking. Applying nutrients based on field experiments so as to estimate the degree of nutrient deficiency or sufficiency levels and to identify the correct nutrient rates is required to optimize crop production. Deficiency of S could also affect the grain yield quality such as protein and oil contents in pulses [12]. The combined effect of P and S on agronomic performance and quality traits of haricot beans grown in Ethiopia has not been well studied. Thus, this study was aimed at investigating the effect of P and S fertilizers on performance of two haricot bean varieties grown under supplementary irrigation in Raya Valley. The paper also attempts to determine the economic profitability of applying P and S fertilizer rates on haricot bean production in the northern Ethiopia.

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MATERIALS AND METHODS

Description of the study area

The study was conducted at Mekoni Agricultural Research Center (Fachagama site) in the Raya Valley, Northern Ethiopia. Geographically, the experimental site is located at 12° 41'50" latitude and 39° 42'08" longitude and at an elevation of 1578 meter above sea level (m.a.s.l). The area is characterized by arid (dry) climate with erratic rainfall distribution and hot temperature. Its annual mean rainfall is 540 mm, where about 80% is received during rainy season with an average minimum and maximum temperature of 22 and 32°C, respectively [13]. The area has clay soil with low soil organic matter, total nitrogen and sulfur contents (Table 1).

The area is characterized by mixed farming system. Sorghum, tef and maize are the major cereal crops whereas chick pea and sesame from pulses and tomato, onion, pepper, mangoes, papaya and avocados are the commonly grown horticultural crops. Cattle, goat, camel, equine, poultry and apiculture are widely distributed livestock species in the study area [14].

Soil sampling and analysis

Soil samples from five randomly selected spots were taken at a depth of 0-20 cm diagonally across the experimental field using auger before planting. The sampled soil was air dried, grounded, and passed through 2 mm sieve and analyzed for physical and chemical properties as presented in Table 1 at Tigray Agricultural Research Institute soil laboratory.

The soil in the area has low total N, soil organic matter (SOM) and S, medium P content and high cation exchange capacity (CEC). Its pH is nearly neutral, which indicates that the soil is suitable for production of most crop types [15, 35, 36].

Experimental Treatments and Procedures

The two bean varieties were selected for their contrasting traits and performance in the field. Melka Awash-98 variety is a canning type while Nasir is a food type [16]. Further description of the two tested varieties is presented in Table 2.

A combination of phosphorus and sulfur (P-S) fertilizers containing three rates of P (10, 20 and 30 kg/ha) and four rates of S (15, 30, 45 and 60 kg/ha) were applied on the two varieties of haricot bean (Melka Awash-98 and Nasir) (Table 3). The experiment was laid out in split plot design where varieties were assigned to the main plots and P-S rates to the sub plots in three replications. Triple super phosphate (Ca $(H_2PO_4)2$) and Gypsum ($CaSO_4.$ $2H_2O$) were used as source of phosphorus and sulfur, respectively. The experiment was laid on 41.5 m by 12.1 m area with the dimension of each plot being 3

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m× 2.4 m (7.2 m^2) with 40 cm intra-row and 10 cm inter row spacing. The spacing between main plots, sub-plots and replications were 75 cm, 50 cm and 100 cm, respectively. Each subplot contained six rows of 3 m long. Starter nitrogen at 13.5 kg ha^{-1} was applied to all treatments during planting as suggested by Amare *et al* [17]. Planting was performed on 23 July, 2016. Weeds were equally controlled manually for all treatments.

Supplementary Irrigation application

Long-term climate data, soil data of the area, rain fall data and crop growth stage (Table 4) were used to determine the supplementary irrigation requirement using CROPWAT 8.0.

The experimental site received 181 mm rainfall in the main cropping season of which 102.8 mm as calculated as effective rainfall (Table 5). For each developmental stage, irrigation was applied at 12 days interval before the depletion point reached the readily available water (RAW) and the amount of applied water was calculated with CROPWAT considering 70% application efficiency for the irrigation method used i.e. furrow irrigation. With this approach, the calculated crop evapotranspiration (ETC) was 329.73 mm, indicating that the net irrigation requirement (NIR) was to be 226.93 mm for optimal growth of the crop. According to their calculated water requirement three and four supplementary irrigations were applied to Nasir and Melka Awash-98 with amount of applied water of 78.5 mm and 122.7 mm, respectively.

Data Collected

Phenological and agronomic data

Phenological data including days to 50% flowering and days to 90% maturity were recorded on plot basis when approximately 50% and 90% of plants in a plot were flowered and matured, respectively. Plant height, number of pods per plant, number of seeds per pod and hundred seed weight were recorded from five randomly sampled plants from the four central rows while grain yield kg ha^{-1} was determined from harvest of four central rows, which makes an account for 4.8 m^2 area per plot.

Grain quality (protein content) data

Grain protein content was determined from grain total nitrogen content [18]. The total grain flour nitrogen content was obtained by methods described by Kjeldahl. To get the crude grain protein content, the amount of total nitrogen recorded was multiplied by the conversion factor of 6.25, which corresponds to the average nitrogen content of the amino acids [18]. The determination of total nitrogen for each sample was carried out at Raya Brewery grain quality analysis laboratory. Then, the crude grain protein content of

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each sample was calculated using the following equation as suggested by Macdonald [18].

$$Protien\ Content(\%) = Nitrogen(\%) x\ 6.25 \ldots\ldots\ldots\ldots 1$$

Economic data

Variable production costs incurred on seeds, applied fertilizers and selling price of haricot bean just after harvest were used to perform partial budget analysis to see economic profitability of each P-S combined fertilizer rate. Other variable costs such as management cost were not considered assuming that they are the same for all treatments. As suggested by CIMMYT [19], the marginal net of return (MRR%) was calculated as a ratio of marginal increase in net benefit to marginal increase in cost where the ratio was multiplied by 100, as indicated in equation below.

$$\mathrm{MRR}(\%) = \frac{\text{Marginal increase in net benefit}}{\text{Marginal increase in cost}} x\ 100 \ldots\ldots\ldots\ldots 2$$

Statistical Analysis

Univariate statistical analysis was performed to analyze the variance (ANOVA) inflicted due to the main effects and their interaction on the measured traits. The analysis was performed using GenStat-18 statistical package at probability level of 5% [20]. Furthermore, whenever the variance was significant, means separation was followed. Means due to the main effects of varieties were separated using least significance difference (LSD, $p<0.05$) while mean separation due to P-S rates main effect and the interaction between the two factors was performed using Duncan Multiple Range Test (DMRT, $p<0.05$). The correlation between a pair of varieties was performed using the same statistical package. Graphs were constructed by using Excel graphing features.

RESULTS AND DISCUSSION

Effect of P-S rates on phenology and morphology of haricot bean

Effect on phenological traits

The interactive effects of the P-S factors revealed significant effects on the phenology of haricot bean. The two varieties significantly ($p<0.05$) differ in their phenology where Nasir is earlier than Melka Awash-98 in flowering and maturity (Table 6). The application of 20kg P ha^{-1} with any rate of S fertilizer was observed to reduce days to flowering (by 1 – 3 days) and days to maturity (by 1- 2 days) compared to 10kg P ha^{-1} or 30kg P ha^{-1}. Variety × P-S rate interaction effect is pronounced on days to flowering but fail to significantly affect days to maturity. Early flowering (49days) was recorded for Nasir variety treated by 20×30 and 20×45kg P-S ha^{-1} while late flowering time was recorded for Melka Awash-98 treated by low rate of P-S fertilizers (Table 7). The

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differential performance in crop phenology could be associated with genetic difference [21] or environmental factors such as soil fertility [10, 22, 23] since the application of fertilizers such as phosphorus and sulfur could hasten the time of maturity in pulse crops particularly haricot bean. The reasons behind hastened phenology could be the role of these mineral nutrients to hasten crop growth and physiological processes. This finding shows that within each rate of P, an increase in S rate could shorten days to maturity in haricot bean.

Effects on Morpho-agronomic traits

Plant height: Combined application of P-S rates affected, to various extents, the morphological and agronomic traits of haricot bean. Plant height, which is the only morphological trait considered, was significantly ($p<0.05$) affected by both main and interaction effects of variety and P-S rate (Table 6). On average, Nasir is taller than Melka Awash-98 by about 3cm and the tallest plant was recorded from 20×30 and 20×45 P-S fertilizer rates. Increasing P rate to 30kg ha^{-1} did not increase plant height in both varieties (Table 7). Variety ×P-S rate affect haricot bean height significantly (Table 7). The tallest heights (50.40 and 50.20cm) were due to the application of 20×30 and 20×45kg ha^{-1} P-S rates while the shortest height (38.97cm) was recorded due to 10kg ha^{-1} of P combined with 15 and 30kg ha^{-1} of S. As P level increased to 30kg ha^{-1}, the height tended to decrease from low to high rate of S although some irregularities were observed. The results confirm that, besides genetic control, height of haricot bean is affected by soil fertility management. The effect of P-S fertilizer application on height of pulses such as faba bean, mung bean and lentil was reported by other scholars [24, 25, 26]. The application P-S increased faba bean height by 15.5% over the control as stated Kissi by [25]. The combination of 20 kg ha^{-1} P with S rates could be an optimum rate to provide balanced nutrient to the plant for maximum vegetative growth to happen.

Pods per plant (NPP): This trait is among the important yield components in haricot bean. The results showed that NPP was significantly affected by varietal differences ($p<0.05$) and P-S rates ($p<0.001$) although there is no pronounced effect due to variety × P-S rate interaction. Considering varieties, on average six more pods per plant were recorded for Nasir over Melka Awash-98 (Table 6). Many pods per plants (~27) were recorded from plots treated with 20×30kg ha^{-1} P-S rate although not statistically different from 20×45 and 20×60kg ha^{-1} P-S rates. On the other hand, the lowest (13.8) NPP was recorded at (10×15kg ha^{-1}) P-S rate combination which clearly indicate that increasing P-S rate to optimal level increases the number of pods per plant and in turn the final grain yield. Number of pods per plant is a key factor in determining the grain yield in leguminous plants [27]. In line with the above finding, [24, 28] reported that combined application of P-S fertilizers significantly increased pod numbers per plant in lentil and chickpea, respectively.

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Seeds per pod (SPP): Number of seeds per pod, with confounded factor of individual seed size and weight, is another ultimate determinant of the final productivity of haricot bean. As observed for other traits, there is significant main effect of variety and P-S rates on this trait as well. Variety Nasir produces pods with more seeds than Melka Awash-98 (Table 6). This infers that varietal difference can be considered to improve yield of haricot bean. SPP tend to increase as the rate of S increased from 15 to 60kg ha^{-1} with the maximum number (~7) of SPP recorded from 20kgP ha^{-1} combined with 30kgS ha^{-1} and 45kgS ha^{-1}. The lowest SPP was recorded from the control plot (Table 6). The interaction effect imposed from variety by P-S rate was not statistically significant.

From lower rate of P (10 kg ha^{-1}), number of seeds per pod tend to increase linearly with increasing rate of S from 15 to 60 kg ha^{-1}. The combination of 30 and 45 kg ha^{-1} S with 20kg ha^{-1} P gave significantly higher (6.6 and 6.7, respectively) NSP compared to other combinations. The increment of P rate beyond 20 kg ha^{-1} with any rate of S did not bring any increment in NSP. Fewer seeds per pod (3.6) were obtained from the lower (10 x 15 kg ha^{-1}) P-S combinations (Table 6). Variety Nasir gave about, on average, 0.8 seeds more than Melka Awash-98. The trait is mainly controlled genetically, but variations like nutrients and water availability may affect from the external environment. It can be inferred that, the difference in the above result could be due to both variety and fertilizer effects. In line with this, the application of 60 x 20 kg per hectare of P-S fertilizer had a significant effect on the number of seeds per plant in chickpea as reported Das *et al.* by [28].

Hundred Seed weight

The result showed significant differences ($P < 0.001$) among P-S rate treatments, varieties and their interaction also significant at ($P < 0.05$) for hundred seed weight. The interaction between varieties and fertilizer shows that, the highest hundred seed weight (28.43 g) was recorded in Nasir variety at treatment combination of 20 x 45 kg ha^{-1}, whereas, significantly lower hundred seed weight (24.20 g) was obtained from Melka Awash-98 in the treatment combination of 30 x 60 kg ha^{-1}, which was at par with those planted at fertilizer rate of 10 x 15 kg ha^{-1} (Table 7). Hundred seed weight tend to be high in Nasir variety (26.50 g) and Melka Awash-98 variety scores relatively low (25.05 g) (Table 6 The differences among the hundred seed weight in these varieties might be due to hereditary superiority, growth rate, crop yield potential, higher nutrient translocation, assimilation and dry matter partitioning. Similar findings were reported by Deshbhratar et al [29] in pigeon pea and in rice, interaction effect of P-S fertilizers being significant on quality trait of the test weight [30]. On the contrary to this finding, it has been reported that for lentil and soybean the effect of different doses of P-S application on seed weight is statistically insignificant [24, 31].

Grain Yield
Analysis of variance showed significant differences ($P < 0.001$) among P-S rate treatments and Varieties ($P < 0.05$) for grain yield, while non-significant response was observed due to their interaction. The increment of P-S rate from 10 x 15 to 20 x 30 kg ha^{-1} has progressively increased grain yield while further increment in P-S rate resulted in decreasing yield. The maximum grain yield (3000 kg ha^{-1}) was obtained from 20 x 30 kg ha^{-1} P-S rate, averaged over varieties. The higher yield from 20 x 30 kg ha^{-1} P-S may have been due to higher number of pods per plant (27.03) and number of seeds per pods (6.60). The minimum grain yield (1520 kg ha^{-1}) was obtained from 10 x 15 P-S with 13.8 and 3.6 number of pods and number of seeds, respectively. Therefore, from the recorded data, the influence of phosphorus and sulfur rate on grain yield was mostly through the increased production of pods per plant and seeds per pod. The mean of grain yield from P-S 20 x 30 kg ha^{-1} was superior by 97.37% over the lowest yield of 10 x 15 kg ha^{-1} P-S rate. Averaged over fertilizers, the maximum grain yield (2510 kg ha^{-1}) was obtained from Nasir variety which exceeds the yield of Melka Awash-98 variety by 470 kg ha^{-1} (Table 6). This might have been due to their difference in dry matter production and its transformation into economic yield and the result of various physiological, bio-chemical, phenological and morphological proceedings taking place in the plant system.

This finding is consistent with that obtained with faba bean, interaction effect of P and S at Agarfa site showing the mean grain yield obtained from combined application of 92 kg P_2O_5 with 30 kg S ha^{-1} was about 23% and 16% higher than the mean seed yield obtained at 0 kg P_2O_5 with 30 kg S $ha^{-1}$and control treatment respectively [25]. It was also reported that the effect of P-S was significant for grain yield in lentil, chickpea and rice, respectively. [24, 28, 30]

Effect of P-S rates on Protein content of haricot bean varieties
The application of combined P-S fertilizers has shown a significant ($P < 0.001$) improvement in haricot bean grain protein content. The difference among the tested varieties and their interaction with the applied fertilizer on grain protein was also remarkably high ($P < 0.001$). Grains harvested from Melka Awash-98 variety treated with 20 x 30 kg ha^{-1} P-S rate contained the highest protein content (27.1%) while the lowest protein content (22.52%) was obtained from Nasir variety treated with P-S rate of 10 x 15 kg ha^{-1}. Considering the main effects of P-S rates, the highest protein content was obtained from 20 x 30 kg ha^{-1} while the lowest content was recorded for 10 x 15 kg ha^{-1}. Comparing the former with the later, 15% protein content gain was achieved. Melka Awash-98 gave highest protein content compared to Nasir variety (Figure 1) at 20 x 30 kg ha^{-1} P-S rate. This could be related to the synthesis of fatty acids and S containing amino-acids such as cysteine and methionine, which are essential components of protein.

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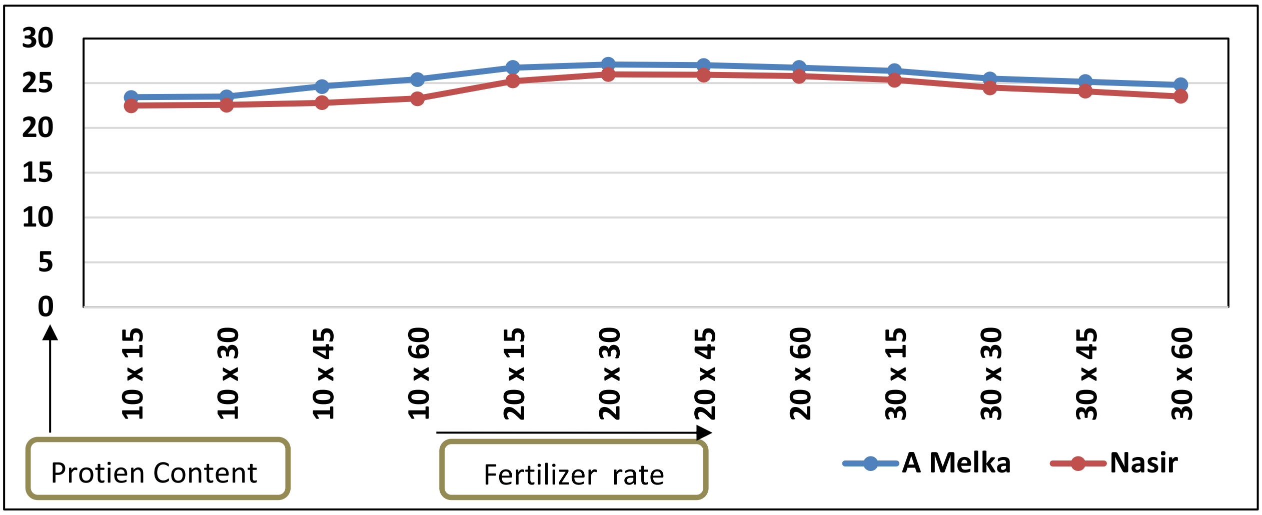

Figure 1: Interaction of Variety x Fertilizer rate on protein content

Haricot beans having 21-25% crude protein, are wealthy in amino acids for instance lysine, but are reasonably deficient in sulfur containing amino acids such as methionine and tryptophan. It has been reported that application of P fertilizer increased haricot bean protein content, although the increment was not linear with P rate [17, 32]. Similar to our findings, it was reported that protein content of chickpea seed was significantly influenced by application of P-S fertilizers [28]. Application of 60 x 20 kg ha^{-1} of P-S increased the protein content of chickpea seed by 9.5% over the control.

Effects of P and S rates on Profitability of Haricot bean Varieties

Partial Budget Analysis

Marginal rate of return (MRR) analysis were significantly affected by treatments (Tables 8). The economic analysis indicated that planting of the variety Melka Awash-98 produced the highest net benefit (19,660 Birr ha^{-1}) with acceptable marginal rate of return compared to Nasir variety. Investing 1 birr in Melka Awash-98 can provide an additional 1.03 birr. Also the highest net benefit with acceptable marginal rate of return (4346 %) was obtained when P-S combination was applied at the rates of 20 x 15 kg ha^{-1}, which means that for every investment in one birr has a return of 43.46 ETB (Tables 8).

In line with the economic profitability of fertilizers, Application of 115 N and 92 P_20_5 kg ha^{-1} with 221 kg ha^{-1} (500 plants/m^2) seed rate, 138 N and 115 P_20_5 kg ha^{-1} with 193 kg ha^{-1} (400 plants/m^2) seed rate and 138 N and 115 P_20_5 kg ha^{-1} with 79 kg ha^{-1} (150 plants/m^2) seed rate reached better economical return with highest grain yield production for Mekelle 3, Mekelle 4 and Danda'a wheat varieties, respectively in southern Tigray [33].

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CONCLUSION

The main effects of the imposed factors manifested significant impact on considered traits than their interaction effects. Grain yield ranged from 1520 to 3000 kg ha^{-1} depending on P-S fertilizer rates and varieties. Grain yield of P-S combination at 20 x 30 kg ha^{-1} was superior by 97.37% from the lowest yielder of 10 x 15 kg ha^{-1}fertilizer rate. With respect to varieties, Nasir seemed to be superior over Melka Awash-98 for most traits except protein content. The grain protein content ranged from 22.52% to 27.10% and the highest value was due to the application of 20 x 30 kg ha^{-1} P-S rate. The partial budget analysis confirms that planting Melka Awash-98 variety could fetch the highest net benefit with acceptable marginal rate of return compared to Nasir variety. Similarly, the highest economic return is obtained from application of 20 x 15 kg ha^{-1} of P-S rate in the study area. Based on the present findings, it might be recommended that combined application of 20 x 30 kg ha^{-1} P-S fertilizers improve grain yield and quality of haricot bean. However, multi-location trials over seasons should be conducted to arrive at conclusive recommendation.

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Table 1: Physical and chemical properties of the experimental soil before planting

Soil Parameters	Values	Ratings	References
Soil Physical properties			
Particle size			
Sand (%)	15		
Silt (%)	27		
Clay %)	58		
Textural Class	Clay		[34]
Soil Chemical properties			
Soil OM (%)	1.95	Low	[35]
Soil PH	6.9	Neutral	[36]
Total Nitrogen (%)	0.10	Low	[36]
Available P (ppm)	6.6	Medium	[37]
Sulfur (mg/kg)	15.2	Low	[11]
CEC (cmolc kg-1)	34	High	[38]
EC (ds/m)	0.12	Salt free	[11]

Table 2: Description of haricot bean varieties used in the study

No	Varieties	Seed color	Seed size	Releasing center	Year of release
1	Melka Awash -98	White	Small	MARC/EIAR	1998
2	Nasir	Red	Big	MARC/EIAR	2003

Table 3: Treatment combinations used in the experiment

S. No	P-S kg ha^{-1}	Haricot bean varieties	
		Melka Awash-98-V_1	Nasir-V_2
1	10 x 15	$V_1P_1S_1$	$V_2P_1S_1$
2	10 x 30	$V_1P_1S_2$	$V_2P_1S_2$
3	10 x 45	$V_1P_1S_3$	$V_2P_1S_3$
4	10 x 60	$V_1P_1S_4$	$V_2P_1S_4$
5	20 x 15	$V_1P_2S_1$	$V_2P_2S_1$
6	20 x 30	$V_1P_2S_2$	$V_2P_2S_2$
7	20 x 45	$V_1P_2S_3$	$V_2P_2S_3$
8	20 x 60	$V_1 2_2 S_4$	$V_2P_2S_4$
9	30 x 15	$V_1P_3S_1$	$V_2P_3S_1$
10	30 x 30	$V_1P_3S_2$	$V_2P_3S_2$
11	30 x 45	$V_1P_3S_3$	$V_2P_3S_3$
12	30 x 60	$V_1P_3S_4$	$V_2P_3S_4$

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Table 4: Length of crop development stages and their Kc values [39]

Growth Stage	Initial	Devt	Mid	End
Days	20	30	40	16
Kc	0.34	0.7	1.01	0.68

Table 5: Frequency of irrigation with amount of water irrigated

Date	NIR mm	GIR mm	RF mm	Peff mm	NIR mm	GIR mm	Area m^2	V Lit	Dis l/s	T s
23-Jul	0	0	11	5.8	0	0	0.9	0	0	0
3-Aug	16.5	23.6	91	48.8	0	0	0.9	0	0	0
15-Aug	18.2	26	33	20.4	0	0	0.9	0	0	0
27-Aug	27.1	38.7	0	0	27.1	38.7	0.9	34.8	3	11.6
8-Sep	38.8	55.4	57	33.6	5.2	7.4	0.9	6.7	3	2.2
20-Se	46.2	65.9	0	0	46.2	66	0.9	59.4	3	19.8
2-Oct	49.2	70.2	0	0	49.2	70.3	0.9	63.3	3	21

Where, NIR = Net irrigation requirement, GIR = Gross irrigation requirement, RF = Rain fall, Peff = Effective rain fall, V = Volume, Dis = Discharge capacity, mm = millimeter, l/s = Liter per second

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Table 6: The main effect of V and P-S rates on yield and yield components of haricot bean

Variety	DF	DM	PH (cm)	NPP	NSP	HSW (g)	YH (kg)	PC (%)
A.Melka	62.72	85.67	43.28	17.15	4.70	25.05	2040	25.55
Nasir	50.25	73.39	46.32	23.09	5.50	26.50	2510	24.31
LSD	1.923	0.316	1.06	1.665	0.562	0.33	1.12	0.018
P-S kg/ha								
10 x 15	57.17a	81.00a	38.97d	13.80d	3.60hi	24.60f	1520a	23.00i
10 x 30	56.67bcd	80.67b	38.97d	14.33d	3.77h	24.87f	1550a	23.04i
10 x 45	57.33a	80.67b	39.37d	14.27d	4.17h	25.03def	1700b	23.75h
10 x 60	57.33a	80.17bc	39.17d	15.03d	4.30g	25.65cd	1840c	24.37f
20 x 15	56.33cde	78.17d	48.30c	23.43b	5.60cd	25.60cde	2700g	26.00c
20 x 30	55.33e	78.17d	50.40a	27.03a	6.60ab	27.38a	3000i	26.55a
20 x 45	55.50e	78.50d	50.30a	26.67a	6.70a	27.37a	2970i	26.48a
20 x 60	55.50e	78.17d	49.77b	25.87a	6.20bc	26.47b	2800h	26.27b
30 x 15	56.50cde	79.67cd	45.53cd	20.90c	5.40de	26.10bc	2460f	25.88cd
30 x 30	56.33cde	79.67cd	45.70cd	20.07c	5.17de	25.80c	2340e	25.00d
30 x 45	56.67bc	79.67cd	45.07cd	19.93c	5.00ef	25.52cdf	2250de	24.67e
30 x 60	57.17b	79.83cd	46.03cd	20.13c	4.70fg	24.98ef	2190d	24.18g
CV	0.7	0.6	3.3	8.3	7.0	3.5	3.5	1.01

Means followed by the same letter in the same column are not significantly different at 5% probability level using Least Significance Difference (LSD), CV = Coefficient of Variance, P-S = Phosphorus-Sulfur Interaction, DF = Days to flowering, DM = Days to maturity, PH = Plant height

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Table 7: Interaction effect of Variety and P-S on DF, PH and HSW of Haricot bean

P-S	DF		PH (cm)		HSW (g)	
kg/ha	A Melka	Nasir	A Melka	Nasir	A Melka	Nasir
10 x 15	63.67a	50.67b	36.53i	41.40h	24.23k	24.97ghijk
10 x 30	62.67a	50.67b	36.47i	41.47h	24.43ijk	25.30fghij
10 x 45	63.67a	51.00b	37.00i	41.733gh	24.30jk	25.77efgh
10 x 60	63.67a	51.00b	37.07i	41.27h	24.80hijk	26.50cde
20 x 15	62.00a	50.67b	49.00b	47.60bcd	24.37ijk	26.83cd
20 x 30	61.67a	49.00b	48.47b	52.33a	26.93bc	27.83ab
20 x 45	62.00a	49.00b	48.47b	52.13a	26.30cdef	28.43a
20 x 60	61.67a	49.33b	47.93bc	51.60a	25.87defg	27.07bc
30 x 15	62.67a	50.33b	44.33efg	46.73bcde	25.07ghijk	27.10bc
30 x 30	62.33a	50.33b	44.80def	46.60bcdef	25.33fghi	26.27cdef
30 x 45	63.00a	50.33b	43.80fgh	46.33bcdef	24.77hijk	26.27cdef
30 x 60	63.67a	50.67b	45.47cdef	46.60bcdef	24.20k	25.77efgh
Mean	62.72	50.25	43.28	46.32	25.05	26.50
CV (%)	0.7		3.3		3.5	

Means followed by the same letter in the same row and column are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT), CV= Coefficient of Variance, P-S=Phosphorus-Sulfur combination. Where DF, PH and HSW are as shown in table 6

Table 8: Partial budget analysis haricot bean varieties

Treatment	GY kg/ha	GY Adjusted	GB ETB/ha	TVC ETB/ha	NB ETB/ha	Dominance Rate	MRR (%)
Variety							
Nasir	25.1	22.6	20340	1350.00	18990	-	-
Melka A-98	20.4	18.4	21160	1500.00	19660	-	103
P-S (kg/ha)							
10 x 15	15.2	13.7	14042.5	1177.5	12865	-	-
10 x 30	15.5	14.0	14350	1427.5	12922.5	-	23
10 x 45	17.0	15.3	15682.5	1677.5	14005	-	433
10 x 60	18.4	16.6	17015	1927.5	15087.5	-	433
20 x 15	27.0	24.3	24907.5	2105	22802.5	-	4346
20 x 30	30.0	27.0	27675	2355	25320	-	1007
20 x 45	29.7	26.7	27367.5	2605	24762.5	D	
20 x 60	28.0	25.2	25830	2855	22975	D	
30 x 15	24.6	22.1	22652.5	3032.5	19620	D	
30 x 30	23.4	21.1	21627.5	3282.5	18345	D	
30 x 45	22.5	20.3	20807.5	3532.5	17275	D	
30 x 60	21.9	19.7	20192.5	3782.5	16410	D	

Where, GY = Grain Yield, GB = Gross Benefit, ETB = Ethiopian Birr (currency);
TVC = Total Variable Cost; NB = Net benefit; MRR = Marginal rate of return, Price for phosphorus Fertilizer = 92.75 ETB kg^{-1}, Price for sulfur Fertilizer = 16.7 ETB kg^{-1}, Price for Haricot bean varieties Melka Awash-98 = 11.5 ETB kg^{-1}, Nasir = 9.0 ETB kg^{-1}, Average price for Haricot bean =10.25 ETB kg^{-1}.

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