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Effect of Phosphorus and Sulphur Fertilizers Application on Faba Bean (*Vicia faba* L) Flowering Stage growth Parameters at Sinana and Agarfa, Southeast Ethiopia

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Original Research Article

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Abstract: Phosphorus and sulphur are one of the most yield limiting nutrients in southeastern part of Ethiopia. Its application is very crucial to increase the productivity of the crop. The experiment was conducted at two locations; Sinana on-farm and Agarfa research sub-site, in the highlands of Bale, Southeast Ethiopia, during the 2012 main cropping season with the objectives of investigating the effect of different rates of P and S fertilizers on some flowering stage growth parameters of faba bean. The treatments consisted of five P rates (0, 23, 46, 69 and 92 kg P_2O_5 ha^{-1}) and three S rates (0, 30 and 60 kg S ha^{-1}). The experiment was laid out in a factorial arrangement of RCBD with three replications. Results indicate that plant height and dry matter production were significantly influenced by P at both locations while S influenced only plant height at Sinana. The interaction effect of P and S influenced plant height and dry matter production only at Sinana. Number of leaf per plant, mean leaf area and leaf area index had significantly influenced by both nutrients and their interaction except no main effect of S on leaf area index at Sinana and mean leaf area at Agarfa. Number of branch per plant and height of first flower bearing node did not affected by the two nutrients. The result of this study showed that to obtain the optimal growth parameters in faba bean at flowering stage under highland condition P and S level at 92 and 30 kg ha^{-1} at Sinana and 92 and 0 kg ha^{-1} at Agarfa can be advised for most parameters respectively.
Keywords: Faba Bean (*Vicia faba* L.), Leaf area index, Node, Nutrient.

INTRODUCTION

In Ethiopia, pulse crops are the second most important food crops next to cereals and occupied about 13 percent of the total cultivated area [1]. Faba bean is one of the oldest food legumes and has been cultivated since antiquity, mainly for human consuption. It is the fourth most important pulse crop in the world [2]. It is precceeded by dry beans (*Phasaleus vulgaris*), chickpeas (*Cicer arietinum*) and cowpeas (*Vigna anguiculata*). Ethiopia and Afghanistan are considered secondary centers of diversity [3]. Nowadays, faba bean is widely grown in temperate and subtropical regions and at higher altitudes in the tropics. In tropical Africa it is mainly found in East Africa, especially in Sudan and Ethiopia [3]. The main producing countries in the world are China, Ethiopia, Egypt and Australia in the decreasing order of their production potential. Ethiopia is second to China in faba bean production area but forth in productivity per unit area after Egypt, Sudan and China in the world [4]. It is the first most important crop among the food legumes in the country.

In Bale Zone of the Oromia Regional State, faba bean is also the leading pulse crop grown in large areas by farmers [5]. It is one of the commonest and cheapest source of protein, generating a considerable household income for the farming community; and it is a valuable break crop in cereal based crop production system. However, the yield of this crop is usually low due to limited use of inputs, especially chemical fertilizers (capable of increasing yields from 10 to 80%), and modern agronomic practices [1] and poor soil fertility [6].

Chemical fertilizers along with adequate amounts of all other growth limiting factors play an important role in increasing crop productivity [7]. Phosphorus (P) and sulphur (S) are among the commercial fertilizers which contribute to the yield of major crops in particular pulse crops. Both nutrients are required by legume crops in larger quantitities than any other nutrients and the crops give good response to them [8 and 9]. Some studies have shown that most Ethiopian soils, similar to the agriucltural soils of the other countries in the tropics, are generally low in nitrogen and phosphorus, which limit crop production [10].

Phosphorus (P) is classified as the second most important element for crop production.It is the first major limiting nutrient in legume crops production. This is because an adequate amount of P nutrition enhances the physiological activities of legume crops, including stimulation of early root formation, growth, nodulation, photosynthesis and flowering [11]. Moreover, the biological nitrogen fixation is a process that is dependent on the energy supplied from the sugars that need to be translocated downward from the host plant shoots [12]. Phosphorus is therefore, the basis for the formation of useful energy, which is essential for sugar formation and translocation. Phosphorus is one of the less mobile plant nutrients in the soil and it can be rendered unavailable to plants. Therefore, the efficiency of plants to use applied phosphorus from the soil is 10 to 30% [13 and 14]. According to [15], seed yields are significantly affected by application of P fertilizer. They observed that the highest seed yield in haricot bean was obtained at 40 kg P_2O_5 ha^{-1}. On the other hand, experiments conducted on effects of P on yields of pea, lentil and faba bean showed that increasing P rates (0, 7, 15, 22, 29, 44 kg P ha^{-1}) resulted in a significant quadratic effect on seed yield [16]. According to them, faba bean was the most responsive crop to P fertilizer application. However, according to [3] most small-scale farmers in Ethiopia were not applied chemical fertilizers to faba bean crop.

Sulphur is another limiting macronutrient which plays many important roles in the growth and development of plants. The main roles of sulphur in legume crops are chlorophyll formation, photosynthesis, development of amino acids, which are the building blocks of plant protein, enhancement of root growth, promotion of nodule formation, enhancing N_2 fixation, and the encouragement of more vigorous plant growth [17]. It is required in large quantities by legume crops than cereals which is associated with nodulation and nitrogen fixation [7]. However, it is probably the fourth most limiting nutrient next to N, P and K in highly weathered soils [18]. Since, it is deficient nutrient in the soil due to low organic matter content of the soils, depletion of the soil reserves due to intensive cultivation, use of high yielding cultivars that remove greater amounts of S from soils, and application of S free fertilizers, accelerated rate of soil erosion, environmental control of sulphur dioxide emissins in industrial areas, increased use of N in the form of urea, and decreased consumption of superphosphate [7]. Ethiopia is also one of the tropical countries in which S deficiency occurs. The Bale Zone of Oromiya Regional State is no exception. This region is an area in which large mechanized crop production has been carried out and characterized by the use of inputs like Diammonium phosphate (DAP) and urea, which do not contain sulphur and thus, has low soil organic matter content. This is also an area where improved high yiedling cultivars that remove higher quantities of sulphur are cultivated. There is also no industrial emmision to the atmosphere and, thus, supply of sulphur from atmospheric deposition is less likely to occur. For this reason one study from Ehiopia showed that an increment of 53% and 95% of nodule number and nodule fresh weight respectively, with application of 30 kg S ha^{-1} using faba bean as a test crop relative to the control treatment in an S-deficient soil [19]. They were also reported that, S application enhanced percent nitrogen derived from atmospher (N_{dfa}) from 55% to 72% and N fixation from 49 to 100 kg N ha^{-1}.

Nutrient requirement of crops depend upon many factors; since there may be synergistic or antagonistic effects of one nutrient on the other [7]. Inline with this many authors reported that application of phosphorus and sulphur to legume has a synergistic effect on many parameters of legumes. This is due to the fact that when sulphur is applied to the soil, it is oxidized by *Thiobacilli* bacteria which leads to production of H_2SO_4, that would then solublize phosphate minerals in the soil [20] which is available to the plant for ease uptake. Accordingly [21], have also reported that there is significant interaction between P and S on seed yield of chickpea in Pakistan. But, in Ethiopia research work regarding integrated use of P and S and their role in legume production is very limited. Therefore, in view of this, the present study was designed to investigate the effect of different rates of P and S fertilizers on some flowering stage growth parameters of faba bean.

MATERIALS AND METHODS

Description of the Experimental Site

The experiment was conducted at two locations in Bale highlands in the Southeast of Ethiopia, namely, Sinana (on-farm) and Agarfa (research sub-station) under rain-fed conditions during "*bona*" season (August-December of 2012) which is the main cropping season. Bale highland is normally characterized by bimodal rainfall patterns which is locally called *'bona'* and *'ganna'* season. The "*bona"* season extends from August-December and "*Ganna"* from March-July. Sinana is located at a distance of about 463 km from Addis Ababa in the South-Eastern direction in the highlands of Bale Zone, South-eastern Oromia, and 33 km East of Robe town, the capital of the Bale Zone. It is located at $7^0$7'N longitude and $40^0$10'E latitude, at an elevation of 2400 meters above sea level [22]. Agarfa is also located at a distance of about 460 km from Addis Ababa in the South-eastern direction situated in the highlands of Bale zone, South-eastern Oromia. It is situated at 38^0 40' to $46^0$3' East longitude and 4^0 to 8^0 11' N latitude at 2350 meters above sea level. The soils of the area are dominated by Cambisol at Sinana and *Vertisol* at Agarfa.

The past twenty-one years (1990-2011) and that of 2012 mean monthly rainfall data at both locations are shown in Figure 1, while the mean maximum and minimum temperatures are presented in Figure 2. Sinana received an annual rainfall of 1439.4 mm during the cropping season (January-December, 2012) whereas, Agarfa received an annual rainfall of 559.2 mm. Total annual rainfall was higher at Sinana than at Agarfa (Figure 1). The mean maximum and minimum temperatures recorded at Sinana station during the growing season were 20.44^{0}C and 9.82^{0}C, respectively while it was 22.45^{0}C and 8.01^{0}C, respectively at Agarfa. This weather data indicated that the two areas are among the potential areas of Bale highlands for pulse crops production, especially, faba bean and field peas, where both crops almost grow twice a year.

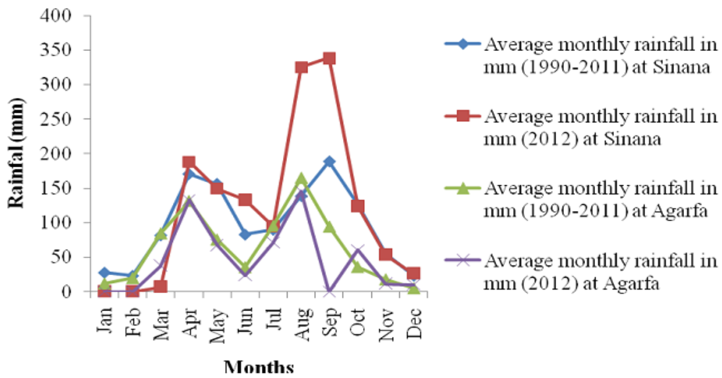

Fig-1: Monthly rainfall during the experimental year (2012) and mean monthly rainfall of past 21 years (1990-2011) at Sinana and Agarfa

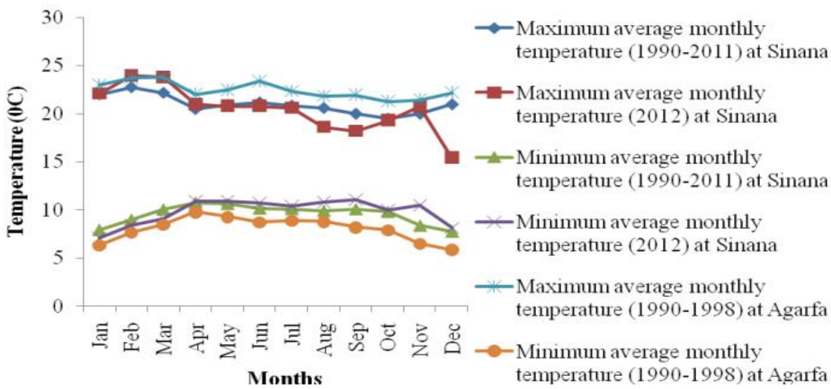

Fig-2: Mean monthly maximum and minimum temperatures (^{0}C) during the experimental year (2012) and of past 21 years (1990-2011) at Sinana and nine years (19990-1998) at Agarfa

Table-1: Selected physico-chemical properties of the experimental soil before planting

Parameters	Location		Parameters	Location	
	Sinana	Agarfa		Sinana	Agarfa
Chemical Properties		Values	Physical properties		Values
pH in water (1:2.5)	7.7	6.7	Particle size distribution (%)		
OC (%)	2.18	1.83	Soil depth (cm)	0-30	0-30
Total N (%)	0.16	0.15	Sand	22	22
Av. P (ppm), Olsen	6.8	11.7	Silt	22	30
CEC (cmol. (+) kg soil^{-1})	49.24	37.38	Clay	56	48
Na^+ (cmol. (+) kg soil^{-1})	0.91	0.91	Textural class	Clay	Clay
K^+ (cmol. (+) kg soil^{-1})	2.19	1.78			
Ca^+ (cmol. (+) kg soil^{-1})	17.81	14.58			
Mg^+ (cmol. (+) kg soil^{-1})	8.1	7.8			
mg kg^{-1} SO_4-S	21.19	19.42			
Bulk density (gcm^{-3})	1.07	1.2			

PH = Soil reaction; OC=Organic carbon; N=Nitrogen; Av. P=Available phosphorus; Na= Sodium, K=Potassium, Ca=Calcium, Mg=Magnesium, SO_4=Sulphate, ppm=Parts per million; CEC= Cation exchange capacity; cmol kg^{-1}=centimole per kg of soil; mg kg^{-1}=milligram

Planting Material

Faba bean (*Vicia faba* L.) variety *"Shallo"* was used as a test crop. It is an improved variety released by Sinana Agricultural Research Centre in 1999/2000, and has average maturity period of about 118 days during its release.

Fertilizer Sources

Phosphorus in the form of triple super phosphate [(TSP) 46% P_2O_5)], Sulphur in the form of Gypsum ($CaSO_4.2H_2O$), with S content of 17.8 % and nitrogen in the form of urea (46% N) were used.

Treatments and Experimental Design

The treatments consisted of five rates of phosphorus (0, 23, 46, 69, and 92 kg P_2O_5 ha^{-1}) and three rates of sulphur (0, 30, and 60 kg S ha^{-1}). The experiment was laid out in a factorial arrangement of randomized complete block design (RCBD) with three replications. Treatments were assigned to each plot randomly. The total number of plots was 45. The size of each plot was 4 m x 3.2 m (12.8 m^2) and distances between the plots and blocks were 1.0 m and 1.5 m respectively. The distance between rows and between plants in the row was 40 cm and 8 cm, respectively. Each plot consisted of 8 rows. 20 kg N ha^{-1} was applied to all plots as starter N. At maturity stage, faba bean plants from the central four rows of a net plot size of 1.6 x 3 m (4.8 m^2) were harvested and used for determining yield and yield components.

Experimental Procedure

Treatment application and field activities

All field activities were done with standard production practices. The land was cultivated by oxen plough (farmers' practice) and pulverized by hand and rows were made to plant the seeds. Application of phosphate, sulphur and nitrogen were done by banding the granules of TSP (Triple superphosphate) (46% P_2O_5) Gypsum ($CaSO_4.2H_2O$) and nitrogen (Urea) was applied around the faba bean seed all at sowing at a rate of (0, 23, 46, 69, and 92 kg P_2O_5 ha^{-1}), (0, 30, 60 kg S/ha) and 20 kg N ha^{-1} respectively. According to research recommendation of the area, the experimental field were twice hand weeded during the growing period to eliminate any external competition by weed. The first weeding was undertaken after 30 days of planting and the second weeding was carried out one month later from the first weeding. Planting of the experiment was done on 20 August 2012 and harvesting was done on 11 January 2012 at Sinana and on 25 August 2012 and 15 January 2012 at Agarfa.

Soil sampling, preparation and analysis

Prior to planting, ten surface soil samples (0-30 cm depth) were taken randomly in a W-shaped pattern from representative spots of the entire experimental field using an auger and composited to one representative samples. This was done after the final ploughing. The composite samples were air-dried at room temperature, thoroughly mixed and ground to pass through a 2 mm sieve and then, analysed for: particle size distribution, pH, organic carbon, cation exchange capacity, exchangeable bases (Na, K, Ca, and Mg), total nitrogen, available sulphur, and available P. The soil was also sampled to analyse bulk density before planting of the crop.

Soil bulk density was determined using a core sampler and soil pH was determined by potentiometric method at 1:2.5 soil: water ratio [23], Cation exchange capacity was determined by 1M ammonium acetate method at pH 7 [24] whereas organic carbon was determined by the Walkley and Black method [25] and total nitrogen by the micro-Kjeldhal method [26], available P was determined by the Olsen method [27]. Available sulphur was analysed by turbidimetric method [28]. Ca^{+2} and Mg^{+2} values were determined using Atomic Absorption Spectrophotometer while Na^+ and K^+ was determined using a flame photometer. Soil particle size distribution was determined by the hydrometer method [29]. Analysis of the soil textural class, pH and available P was done at the soil laboratory of Sinana agricultural research center while total N, available S, exchangeable bases, organic carbon and CEC were analysed at soil and plant analyses laboratory of Holeta agricultural research centre.

Data Collection

Plant height at 50% flowering Stage

From six rows of each experimental plot, the height of five randomly selected plants was measured from ground to the tip (apical bud) and the means were recorded as plant height (cm) at 50% flowering stage.

Dry matter yield at 50% flowering stage

Dry matter yield of the plant was determined at 50% flowering stage of the crop from five plants. The plant samples were placed in labeled perforated paper bags and oven-dried at 70^0c to a constant weight to determine the dry matter yield. The average dry weight per plant was determined for each plot.

Number of leaf per plant

Five plants were randomly selected for counting the number of leaves per plant at the end of the flowering stage and the mean number of leaves per plant was calculated.

Leaf area and leaf area index

Leaf area was calculated at the end of the flowering stage by randomly selecting five plants from the non border rows of each plot. The mean leaf area was obtained as the average leaf area of three leaves which were obtained from top, middle and bottom parts (one leaf from each part) per plant. Actual leaf area of each lamina (leaf) was determined by tracing an individual leaf onto a square paper with a dimension of 0.25 cm^2 per square and by counting the number of squares covered by the leaf and multiplying it by the dimension of the square. In this case, the peripheral squares with an area greater or equal to 0.125 cm^2 were considered as full squares and squares below this area were not considered. Total leaf area per plant was calculated based on mean leaf area per plant multiplied by total number of leaf per plant. Similarly, leaf area index was calculated as the ratio of total leaf area per area of land (cm^2) occupied by the plant, i.e.

LAI = TLA/LA ……………….. (1)

Where,
LAI = Leaf area index, TLA = Total leaf area per plant and
LA = Area of the land occupied by the plant

Number of branches per plant

Five plants were randomly selected for counting the number of branches per plant at 50% flowering stage and the mean number of branches per plant was determined.

First flower bearing node

It was determined by counting from the base of the plant to the node at which flower setting started.

DATA ANALYSIS

Data were subjected to analysis of variance following the standard procedure given by [30] and analysis was made using SAS GLM procedure [31]. Comparisons among treatment means with significant difference for measured and scored characters were done using Duncan's multiple range test [32] at 5% probability level.

RESULTS AND DISCUSSION

Plant height at 50 percent flowering stage

Analysis of variance showed significant ($P \leq 0.001$) statistical differences due to individual effect of P for plant height at 50% flowering stage at both locations. However, S showed non- significant effect at both location (Table 2 and 3). The individual effect of P at Agarfa site showed application of P at a rate of 92 kg P_2O_5 ha^{-1} resulted in about 13.1% and 9.6% increment in plant height as compared to control treatment and 23 kg P_2O_5 ha^{-1}. This may be probably due to the cumulative effect of P on the processes of cell division and balanced nutrition [33]. These results are in accordance with the findings of [34] who have reported an increase in plant height of faba bean both at 50% flowering and maturity stage in response to increased P application. Similarly [35], has also observed an increase in plant height of fenugreek genotypes at 50% flowering stage in response to P fertilization.

Analysis of variance also showed there was highly significant ($P < 0.01$) variation due to interaction effect of P and S at Sinana while no interaction effect was observed at Agarfa (Table 2 and 3). The increment in plant height by about 15.5% was observed for combined application of 92 kg P_2O_5 with 30 kg S ha^{-1} and 69 kg P_2O_5 with 60 kg S ha^{-1} compared with the control. The increase in plant height under both nutrients might be due to their effect on metabolism of growing plants, favoring growth, yield and yield parameters [36].

Dry matter yield at 50 percent flowering stage

Data on main effect of P on dry matter yield at 50% flowering stage is presented in Table 2 and 3. The result showed that the main effect of P fertilization had significant ($P \leq 0.001$) influence on dry matter yield at 50% flowering stage at both locations. The application of P at 69 kg P_2O_5 ha^{-1} increased the dry matter yield by about 32.5% compared to the control treatment at Agarfa. This may probably be due to P has an enhancing impact on plant growth and biological yield through its importance as energy storage and transfer necessary for metabolic processes [37] and it also raised the efficiency of plants to photosynthesis, enhances the activity of rhizobia [38]. This result is also in agreement with the findings of [34] who have reported that P application to faba bean at 60 kg P ha^{-1} resulted in approximately 57% increment in biomass yield at 50% flowering and maturity stage as compared to the control treatment.

Similarly, the data revealed that interaction of P and S had significant ($P \leq 0.05$) effect on dry matter yield at Sinana, while it has no significant effect at Agarfa. The application of P and S at the rate of 92 kg P_2O_5 with 30 kg S ha^{-1} increased the dry matter yield by about 50.7% and 47.3% compared with 0 kg P_2O_5 with 60 kg S ha^{-},^{1} and 0 kg P_2O_5 with 30 kg S ha^{-1} and the control treatment, respectively (Table 2). Similar to result of Agarfa site [39], have reported that interaction of P and S hadn't significant for dry matter production of soybean at maturity. On the other hand, the results revealed that there was no main effect of S fertilization on dry matter production at both locations and also no interaction effect of P and S at Agarfa.

The combined analysis revealed that location and P had significant influence on mean dry matter yield. It was observed that plants grown at Sinana produced significantly higher dry matter yield than those grown at Agarfa site (Table 5). Thus, at Sinana more dry matter yield per plant was accumulated (about 15.9%) than at Agarfa. This may be due to the cumulative effect of *rhizobium* bacteria which showed more nodules fresh and dry weight and volume per plant, which in turn might have contributed to more N_2 fixation and dry matter production.

Table-2: Interaction effects of phosphorus and sulphur rates on plant height and dry matter yield per plant at 50% flowering stage at Sinana

	Plant height (cm)				Dry matter yield (g plant^{-1})			
	Sulphur (kg S ha^{-1})							
Phosphorus (kg P_2O_5 ha^{-1})	0	30	60	Mean	0	30	60	Mean
0	88.3^{f}	91.5^{cde}	89.0^{ef}	89.6^{c}	10.57^{fg}	10.57^{fg}	9.85^{g}	10.3^{c}
23	89.4^{ef}	91.0^{def}	91.8^{cde}	90.7^{c}	12.67^{d-g}	13.76^{def}	13.77^{def}	13.4^{b}
46	93.5^{cd}	98.5^{b}	94.4^{c}	95.5^{b}	14.74^{b-e}	11.16^{efg}	15.62^{bcd}	13.8^{b}
69	97.9^{b}	100.6^{b}	104.5^{a}	101.0^{a}	17.73^{abc}	17.84^{abc}	18.49^{ab}	18.0^{a}
92	100.5^{b}	104.4^{a}	100.1^{b}	101.6^{a}	14.16^{c-f}	20.07^{a}	16.12^{bcd}	16.8^{a}
Mean	93.9	97.2	95.9	95.7	13.9	14.8	14.8	14.5
	P	S	P x S		P	S	P x S	
SE(±)	0.55	ns	0.95		0.67	ns	1.16	
CV(%)				1.7				13.9

Means followed by same letter(s) are not significantly different at 5% probability levels following DMRT, SE = Standard errors of the mean, CV = Coefficient of variation, ns = non-significant, P = Phosphorus, S = Sulphur

Table-3: Main effects of phosphorus rates on plant height and dry matter production at 50% flowering stage at Agarfa

Phosphorus (kg P_2O_5 ha^{-1})	Plant height (cm)	Dry matter Yield (g/plant)
0	90.0^{c}	10.02^{c}
23	93.6^{c}	11.84^{bc}
46	98.6^{b}	11.71^{bc}
69	102.5^{ab}	14.85^{a}
92	103.6^{a}	12.69^{b}
Mean	97.7	12.2
SE(±)	1.65	0.65
CV (%)	5.1	15.9

Means followed by same letter(s) are not significantly different at 5% probability levels following DMRT, SE = Standard errors of the mean, CV = Coefficient of variation, ns = non significant

Number of leaf per plant, mean leaf area and leaf area index

The analysis of variance showed that there were significant variations (P<0.001) in mean area of individual leaves (MLA), number of leaves per plant (NLP) and leaf area index (LAI) for P levels at 50% flowering stage at both locations. The results also showed significant variations were observed due to main effect of S on MLA and NLP at Sinana and NLP and LAI at Agarfa. However, there is no significant main effect of S on LAI at Sinana and MLA at Agarfa (Table 4).

Similarly, analysis of variance also showed that significant variations (P<0.001) for the interaction between P and S rates on these three parameters at both locations. The result showed higher mean leaf area (40 and 31.9 cm^2) for application of 92 kg P_2O_5 with 30 kg S ha^{-1}, and 92 kg P_2O_5 with 0 kg S ha^{-1}, more number of leaf per plant (184 and 153) for 92 kg P_2O_5 with 30 kg S ha^{-1} and 46 kg P_2O_5 with 0 kg S ha^{-1}, and large leaf area index (23 and 13.8) for 92 kg P_2O_5 with 30 kg S ha^{-1} and 92 kg P_2O_5 with 0 kg S ha^{-1} at Sinana and Agarfa respectively. This implies that leaf parameters were highly responsive to P at the maximum rate while it responded to sulphur at lower rate. This might be due to low availability of soil P as compared to available soil S at study areas. On the other hand, the high response of the plant to applied P might be due to P can improve the rate of assimilate production per unit leaf area, as it is involved in photosynthetic energy transfer processes. The result was in agreement with the findings of [40] who reported P application at rates of 30 and 60 Kg P_2O_5 ha^{-1} significantly increased LAI of Dekoko (*Pisum sativum* var. *abyssinicum*) under field conditions. This result is also in agreement with that of [41] who reported that the number of leaves per plant and leaf area index tended to increase with the application of S up to 60 kg ha^{-1} which conducted on rapeseed (*Brassica campestris* L.). The authors also noted that further increases in S rate tended to depress the number of leaves per plant due to toxic effects. Similarly, [42] also reported that the number of leaves of sunflower tended to increase with application of S up to 60 kg S ha^{-1} and then declined.

The Combined location analysis showed that significant main effects of P and location and interaction effects of location x S, location x P, P x S and location x P x S on leaf parameters. However, the main effect of S revealed that S had influenced only number of leaf per plant (Table 8).

The interaction effect of location x P rate was significant (P≤0.001) for mean leaf area (MLA), number of leaves per plant (NLP), and LAI, where higher values of the three parameters were recorded at Sinana. Accordingly, the higher MLA, more NLP, large LAI (37.6 cm^2, 155.8 and 18.1) was observed at 69, 92 and 69 kg P_2O_5 ha^{-1} respectively at Sinana, while the lowest values for the respective parameters were observed at P rates of 23 kg P_2O_5 ha^{-1} at Agarfa and lowest number of NLP (111.4) at 0 kg P_2O_5 ha^{-1}at Sinana site (Table 4). MLA and LAI had higher values at Sinana than at Agarfa probably due to P effect, while higher number of leaves per plant was observed at Agarfa. This is related to more response of the crop to applied P in MLA and LAI at Sinana due to P can improve the rate of assimilate production per unit leaf area, as it is involved in photosynthetic energy transfer processes. At Agarfa more NLP is related to large plant height is produced by P at late flowering stage.

The interaction effect of location x S rates showed decreasing trend for MLA and LAI as S levels increased from nil to the maximum at Sinana while no variation in MLA and increased trend for LAI at Agarfa. Thus, large MLA and LAI were recorded for the control treatment at Sinana and large LAI was recorded at 60 kg S ha^{-1} at Agarfa (Table 4). This indicated that Sinana site responded less to applied S than Agarfa site with regard to leaf parameters. In general large MLA and LAI were observed at Sinana whereas, more NLP was observed at Agarfa.

Table-4: Interaction effects of phosphorus and sulphur rates on mean leaf area, number of leaves per plant and LAI at Sinana and Agarfa

Phosphorus (kg P_2O_5 ha^{-1})	Sinana											
	Mean leaf Area (cm^2)				Number of leaf $plant^{-1}$				Leaf Area Index			
	Sulphur level (kg S ha^{-1})											
	0	30	60	Mean	0	30	60	Mean	0	30	60	Mean
0	35.2^{c}	32.5^{d}	35.0^{c}	34.2^{b}	116.7^{de}	121.5^{de}	95.9^{f}	111.6^{c}	12.8^{efg}	12.3^{fg}	10.5^{h}	11.9^{c}
23	37.0^{b}	32.5^{d}	32.0^{d}	33.8^{b}	117.3^{de}	110.6^{e}	121.9^{de}	116.6^{c}	13.5^{ef}	11.2^{hg}	12.2^{fg}	12.3^{ab}
46	38.0^{b}	28.5^{e}	38.0^{b}	34.8^{ab}	130.9^{cd}	143.0^{bc}	128.9^{cd}	134.3^{b}	15.5^{d}	12.7^{efg}	15.3^{d}	14.5^{b}
69	39.9^{a}	34.8^{c}	38.2^{b}	37.6^{a}	147.7^{b}	144.0^{bc}	170.6^{a}	154.1^{a}	18.4^{c}	15.7^{d}	20.3^{b}	18.1^{a}
92	34.5^{c}	40.0^{a}	31.9^{d}	35.4^{ab}	141.7^{bc}	184.0^{a}	141.8^{bc}	155.8^{a}	15.2^{d}	23.0^{a}	14.1^{de}	17.5^{a}
Mean	36.9^{a}	33.7^{b}	35.0^{ab}	35.16	130.9^{b}	140.6^{a}	131.8^{b}	134.5	15.1	15.0	14.5	14.86
	P	S	P x S		P	S	P x S		P	S	P x S	
SE(±)	0.25	0.19	0.43		2.76	2.14	4.78		0.32	ns	0.55	
CV (%)				2.1				6.2				6.4
Phosphorus (kg P_2O_5 ha^{-1})	Agarfa											
	Mean leaf Area (cm^2)				Number of leaf $plant^{-1}$				Leaf Area Index			
	Sulphur level (kg S ha^{-1})											
	0	30	60	Mean	0	30	60	Mean	0	30	60	Mean
0	25.6^{def}	24.3^{f}	29.8^{ab}	26.6^{b}	141^{abc}	142^{bc}	126^{e}	136.4^{bc}	11.3^{def}	10.7^{f}	11.8^{c-f}	11.3^{b}
23	27.0^{cde}	24.8^{ef}	24.3^{f}	25.4^{b}	137^{acd}	138^{cd}	151^{ab}	142.1^{ab}	11.6^{def}	10.7^{f}	11.5^{def}	11.2^{b}
46	25.2^{def}	28.4^{bc}	26.2^{c-f}	26.8^{b}	153^{a}	137^{cd}	150^{ab}	146.7^{a}	12.0^{b-e}	12.1^{b-e}	12.3^{b-e}	12.2^{a}
69	26.5^{c-f}	29.9^{ab}	26.4^{c-f}	27.6^{b}	135^{cde}	139^{cd}	151^{ab}	141.4^{ab}	11.1^{ef}	12.9^{abc}	12.4^{bcd}	12.2^{a}
92	31.9^{a}	27.8^{bcd}	32.0^{a}	30.6^{a}	139^{cd}	129^{de}	131^{de}	133.0^{c}	13.8^{a}	11.2^{def}	13.1^{ab}	12.7^{a}
Mean	27.3	27.0	27.8	27.4	141.0^{ab}	137.1^{b}	141.8^{a}	139.9	11.9^{ab}	11.5^{ab}	12.2^{a}	11.92
	P	S	P x S		P	S	P x S		P	S	P x S	
SE(±)	0.46	ns	0.80		1.73	1.34	2.99		0.22	0.17	0.38	
CV (%)				5.1				3.7				5.6

Means followed by same letter(s) are not significantly different at 5% probability levels following DMRT, SE = Standard errors of the mean CV = Coefficient of variation, P = Phosphorus, S = Sulphur, ns = non-significant.

The interaction effects of location x P x S showed that highest number of leaves per plant (184), and large mean leaf area (40 cm^2) and leaf area index (23 cm^2) were observed at combined application of 92 kg P_2O_5 with 30 kg S ha^{-1} at Sinana while the lowest number of leaves per plant (96) and small mean leaf area (24.3 cm^2) and leaf area index (10.5 cm^2) were recorded at the combined application of 0 kg P_2O_5 with 60 kg S ha^{-1}, and 0 and 23 kg P_2O_5 with 30 kg S ha^{-1} and 0 kg P_2O_5 with 60 kg S ha^{-1} at Sinana, Agarfa and Sinana site respectively (Table 4).

As indicated in Table 4, it was observed that larger mean leaf area and leaf area index were recorded at Sinana, while significantly higher number of leaves per plant were recorded at Agarfa. This shows that, at Sinana there was more interception of sun light energy which is an essential variable to obtain high seed and dry matter yield as compared to Agarfa site. It has been reported that leaf area is positively correlated with yield [36] as it was an important component having a large bearing on the physiological processes controlling yield and dry matter production.

First flower bearing node

The analysis of variance showed that no significant variation was observed due to main effects as well as interaction of P and S fertilizer rates on the height of first flower bearing node at both locations (Table 6). However, combined analysis showed only test location had significant variations on height of first flower bearing node (a node at which flower setting begins). Accordingly, flower setting started at 6^{th} node at Sinana as compared to Agarfa which begun at 9^{th} node (Table 5 and 6). This means that first flower appeared at 6^{th} node from the ground to upwards at Sinana and at 9^{th} nodes at Agarfa. From the yield attribute point of view, this is considered as a merit of the plant. Since, pod per plant was one criterion for yield components [7], which affect yield per unit area. Generally, from this result it was observed that, when flower setting is started few meters above the ground, there is an opportunity to get more number of pods per plant, as a result, more yields per unit area will be realised. Thus, more yields will be realised from Sinana site than Agarfa, due to flower setting was started few meters above ground at Sinana as to Agarfa.

Table-5: Main effects of location on some 50% flowering stage parameters combined over

Location	PHF	DMP	BPP	FFBN	NLP	MLA	LAI
Sinana	95.7	14.5^a	2.7^a	6.4^a	134^b	35.2^a	14.9^a
Agarfa	97.7	12.2^b	1.3^b	9.0^b	140^a	27.3^b	11.9^b
Mean	96.7	13.3	2.0	7.7	137	31.2	13.4
SE (±)	ns	0.29	0.07	0.09	1.04	0.16	0.12
CV (%)	6.58	22.78	23.4	7.7	5.1	3.5	6.1

Means followed by same letter(s) are not significantly different at 5% probability levels following DMRT, CV= Coefficient of variation, PHF = plant height at 50% flowering, DMP = Dry matter production, BPP = Branch per plant, FPBN = First flower bearing node, NLP = Number of leaf per plant, MLA = Mean leaf area, LAI = Leaf area index.

Number of branches per plant

The number of braches per plant was observed to be not significantly affected by the different rates of P and S at both locations (Table 6). Similarly, it was not influenced by the interaction of P and S at both sites. The combined analysis showed only location had significantly affected the number of branches per plant. Accordingly, more mean number of branches per plant (2.7) was produced at Sinana as compared to Agarfa (1.3$plants^{-1}$) (Tables 5 and 8). In contrast to this result, [34] have reported that P fertilization had a significant effect on the number of branches per plant at maturity. They have noted that the significant difference might be due to the variability of available P and other nutrients, the environmental conditions and genotype difference on which the experiments were conducted. In line with these factors, the difference in branch per plant between the two locations may be due to differences in soil and environmental factors between the two locations.

Table-6: Interaction effects of P and S rates on number of branches per plant, height of first flower bearing node and pod per node at Sinana, Agarfa and Combined over location

	Sinana		Agarfa		Combined over location	
Treatment combination	No. of Branch/ Plant	Height of first flower	No. of Branch/ Plant	Height of first flower	No. of Branch/ Plant	Height of first flower
P0S0	2.6	6.2	1.3	9.5	1.9	7.8
P_0S_{30}	2.4	6.9	1.2	8.8	1.8	7.9
P_0S_{60}	2.5	6.6	1.8	8.6	2.1	7.6
$P_{23}S_0$	3.2	6.1	1.4	9.4	2.3	7.8
$P_{23}S_{30}$	2.9	5.9	1.0	8.6	2.0	7.3
$P_{23}S_{60}$	2.6	6.5	1.2	9.2	1.9	7.8
$P_{46}S_0$	3.1	6.6	1.5	8.7	2.3	7.7
$P_{46}S_{30}$	2.7	6.5	0.9	9.2	1.8	7.8
$P_{46}S_{60}$	2.9	6.7	1.1	9.2	2.0	8.0
$P_{69}S_0$	2.9	6.3	1.9	8.9	2.4	7.6
$P_{69}S_{30}$	2.7	5.8	1.7	8.6	2.2	7.2
$P_{69}S_{60}$	2.7	6.5	1.1	9.5	1.9	8.0
$P_{92}S_0$	2.6	6.7	1.6	8.7	2.1	7.7
$P_{92}S_{30}$	2.2	5.6	1.3	8.9	1.8	7.2
$P_{92}S_{60}$	3.3	6.5	1.3	9.1	2.3	7.8
Mean	2.7	6.4	1.3	9.0	2.0	7.7
SE (±)	ns	ns	ns	ns	ns	ns

P= Phosphorus, S = Sulphur, ns = non-significant

Table-7: Mean squares for 50% flowering and late flowering stage parameters of faba bean as influenced by P and S rates and their interactions at Sinana and Agarfa

Source of Variation	Sinana							
	df	BPP	DMP	PHF	FFBN	NLP	MLA	LAI
Replication	2	0.66	3.80	6.16	0.585	126.75	0.39	2.31
S	2	0.36^{NS}	2.86^{NS}	41.19^{***}	0.621^{NS}	433.88^{**}	39.34^{***}	1.48^{NS}
P	4	0.27^{NS}	82.40^{***}	281.46^{***}	0.398^{NS}	3816.37^{***}	20.22^{***}	74.10^{***}
P x S	8	0.28^{NS}	10.83^{*}	10.85^{**}	0.373^{NS}	699.2^{***}	38.04^{***}	25.28^{***}
Error	28	0.26	4.06	2.68	0.211	68.61	0.55	0.92
Source of Variation	Agarfa							
	df	BPP	DMP	PHF	FFBN	LPP	LAPL	LAI
Replication	2	0.04	0.84	40.12	0.22	0.20	3.25	0.57
S	2	0.36^{NS}	8.19^{NS}	25.31^{NS}	0.38^{NS}	91.46^{*}	1.95^{NS}	1.62^{*}
P	4	0.27^{NS}	27.85^{***}	302.31^{***}	0.03^{NS}	253.36^{***}	34.65^{***}	3.73^{***}
P x S	8	0.28^{NS}	4.35^{NS}	18.59^{NS}	0.43^{NS}	205.13^{***}	16.48^{***}	1.97^{***}
Error	28	0.17	3.78	24.49	0.47	26.89	1.91	0.44

BPP = Branch per plant, DM = Dry matter production, PHF = Plant height at 50% flowering stage, FFBN = First flower bearing node, NLP = Number of leaf per plant, MLA = Mean leaf area LAI = Leaf area index, df = degree of freedom, *, **, ***, Significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively, NS = Non-Significant

Table-8: Mean squares for some 50% flowering stage parameters of faba bean as influenced by phosphorus and sulphur rates and their interactions combined over locations

Source of Variation	df	BPP	DMP	PHF	FFBN	NLP	MLA	LAI
Replication	2	0.009	2.39	29.149	0.092	59.08	2.65	2.39
Location	1	43.960^{***}	113.86^{***}	86.828^{**}	155.24^{***}	681.72^{***}	1387.19^{***}	196.38^{***}
S	2	0.752^{NS}	9.91^{NS}	1.849^{NS}	0.97^{NS}	71.29^{NS}	22.33^{***}	0.55^{NS}
P	4	0.090^{NS}	100.70^{***}	578.365^{***}	0.21^{NS}	1859.21^{***}	38.85^{***}	53.61^{***}
Loc x P	4	0.409^{NS}	9.55^{NS}	5.407^{NS}	0.22^{NS}	2210.53^{***}	16.02^{***}	24.22^{***}
Loc x S	2	0.027^{NS}	1.14^{NS}	64.662^{**}	0.03^{NS}	454.05^{***}	18.96^{***}	2.56^{*}
P x S	8	0.255^{NS}	6.07^{NS}	21.84^{NS}	0.339^{NS}	591.17^{***}	14.74^{***}	8.84^{***}
Loc x P x S	8	0.253^{NS}	9.11^{*}	7.59^{NS}	0.463^{NS}	313.16^{***}	39.78^{***}	18.41^{***}
Error	58	0.231	3.87	13.71	0.35	48.44	1.22	0.67

BPP = Branch per plant, DM = Dry matter production P, PHF = Plant height at 50% flowering stage, FFBN = First flower bearing node, NLP = Number of leaf per plant, MLA = Mean leaf area LAI = Leaf area index, df = degree of freedom, *, **, ***, Significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$ respectively, NS = Non-Significant

CONCLUSION

Application of P and S significantly affected all considered leaf parameters at both locations while no significant effect on number of branch per plant and height of first flower bearing node. Plant height and dry matter yield was significantly affected by P than S. Thus, this study showed that to obtain the optimal growth parameters in faba bean at flowering stage under highland condition P and S level at 92 and 30 kg ha^{-1} at Sinana and 92 and 0 kg ha^{-1} at Agarfa can be advised for most growth parameters respectively.

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