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Response of Faba Bean (*Vicia faba* L.) to Phosphate Fertilizer Rates and Plant Population Density in the Highlands of Jimma Zone South Western Ethiopia

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Keywords

Faba bean,
Plant population,
Phosphorus,
Seed rate, and
Fertilizer rate

Abstract

Faba bean is an important pulse crop grown in the highlands (1800–3000 m.a.s.l) of Ethiopia, where the need for a chilling temperature is satisfied. However, the productivity of faba beans in Ethiopia is still far below its potential due to several constraints, such as lack of optimum plant population density and fertilizer rate. At Jimma there was no optimum recommendation of plant population density and P fertilizer rate, so the farmers and researchers uses the blanket recommendation of 250,000 plants ha^{-1} (40cm inter row with 10cm intra row spacing) and P fertilizer rate of 46 kg P_2O_5 ha^{-1}. Hence, a field experiment was conducted to determine the optimum plant population density and P fertilizer rate for the crop production at Jimma Dedo district during the 2019 to 2021 main cropping seasons. The factorial combinations of phosphate fertilizer (23, 46, and 69 kg P_2O_5 ha^{-1}), and plant population densities of 476,190 (30*7cm), 333,333 (30*10cm), 256,410 (30*13cm), 357,143 (40*7cm), 250,000 (40*10cm), 192,308 (40*13cm), 285,714 (50*7cm), 200,000 (50*10cm), 153,846 (50*13cm) plants ha^{-1} were laid out in a randomized complete block design with three replications. A starter amount of nitrogen (N) fertilizer at the rate of 19 kg ha^{-1} was applied uniformly to all treatments per plots. Accordingly, the significant highest grain yield of 4.79 t ha^{-1} and highest net benefit of 135,444 Ethiopian Birr ha^{-1} with acceptable marginal rate of return of 671% was recorded from interaction effect of 46 kg P_2O_5 ha^{-1} fertilizer rate together with 10 cm intra-row-and 50 cm inter-row spacing (200,000 plants ha^{-1}). Thus the fertilizer rate of 46 kg P_2O_5 ha^{-1} and N at the rate of 19 kg ha^{-1} together with plant population density of 200,000 plants ha^{-1} (10 cm intra-row-and 50 cm inter-row spacing equivalent to 20 plants per square meter) was found to be optimum for faba bean production in South Western Ethiopia (Jimma areas) of acidic nitisols and similar agro-ecologies.

Introduction

Faba bean *(Vicia faba* L.) is one of the major pulse crops grown in the highlands (1800–3000 m.a.s.l) of Ethiopia, where the need for a chilling temperature is satisfied [1]. It is grown largely by subsistence farmers during the cool season [2]. Faba bean takes the largest share (30.12%) of the area under pulse production [3]. It is well adapted to the diverse soil types of Ethiopia, where legumes are prominently used as traditional soil fertility restoration crops in mixed cropping systems [4]. Also, it is noted that among the major cool-season grain legumes, faba bean has the highest average reliance on N_2 fixation for growth [5]. Hence, the use of faba bean in crop rotation had a significant effect by reducing the amount of chemical nitrogen applied to soil for crop production [4]. However, the production and productivity of faba beans is constrained by several biotic and abiotic stresses. Among which, optimum plant density and lack of optimum fertilizer recommendation are two of the most important cultural practices determining grain yield, as well as other important agronomic attributes of the crop [6]. It is also to be noted that plant population or seed rate is influenced by row width, crop species, soil and climatic variables, and crop use. Hence, maximizing economic returns within the constraints of a specific environment is a major research objective [7]. When the environment becomes favorable, the optimum population will increase [8] and as the level of available soil nutrients increases, the need for fertilizer decreases.

When legume plants are supplied with phosphorus at optimal rates, vigorous plant growth as well as increased assimilate formation and translocation to plant fruiting parts results in improved development of seed yield and its components [9]. The application of phosphorus fertilizer ranging from 20 kg P ha^{-1} in various locations to 40 kg P ha^{-1} in the Bore highlands and at Sekela produced higher grain yields [10, 11, 12].

For most crops, including faba bean, the choice of seeding rate is an important agronomic practice that influences plant density and crop establishment as it is a major determinant of proper plant development and growth [13]. Both high and low crop densities reduce yield and total revenue [14]. It has been reported that among improved production technologies, proper plant population with appropriate adjustment of inter- and intra-row spacing plays a key role in enhancing faba bean production [15]. A wide range of optimum plant densities are reported depending on the faba bean cultivar, environmental conditions (soil type, soil moisture, soil fertility, and relative humidity), and the sowing date [16]. Furthermore, a few research findings on intra-row-and inter-row spacing revealed varying results under various environmental conditions. Accordingly, an intra-row spacing in the range of 5 to 15 cm and an inter-row spacing of 30 to 40 cm have been recommended at different localities depending on different environmental conditions [16].

However, most of the above recommendations didn't consider the combined effect of spacing and fertilizer application. In addition, no recommendations have been made so far considering specific soil and environmental conditions such as acid-prone areas. At Jimma there was no optimum recommendation of plant population density and P fertilizer rate, so the farmers and researchers uses the blanket recommendation of 250,000 plants ha^{-1} (40cm inter row with 10cm intra row spacing) and P fertilizer rate of 46 kg P_2O_5 ha^{-1}. Hence, this experiment was conducted to determine optimum spacing in combination with an optimum phosphorus application rate of faba bean for highland area of Jimma zone.

Materials and Methods

Area description

The field experiment was conducted at Jima zone Dedo district in the period from 2019 to 2021 under rain-fed conditions during the main cropping season. It is located in Oromia Regional State at a distance of about 373 km from Addis Ababa in the south-western direction, at $7^0$29'930" northern latitude and 36°51'47" eastern longitude, at an elevation of 2325 meters above sea level. As depicted in figures 1 and 2, three-year rainfall and temperature data for growing period of the crop at the Dedo district was presented in this report respectively. A lower amount of total rainfall was recorded in 2021 (818.80 mm) than in the year 2019 (825.9 mm) and 2020 (882.2mm) for the growth period (July to December) of faba bean. There was rainfall throughout the crop growth period (July to December) at Dedo district in all three years, with a decreasing trend. At the year 2019 and 2020 seemed more favorable for faba bean yield production and also the yield differences displayed this fact (Figure 3).

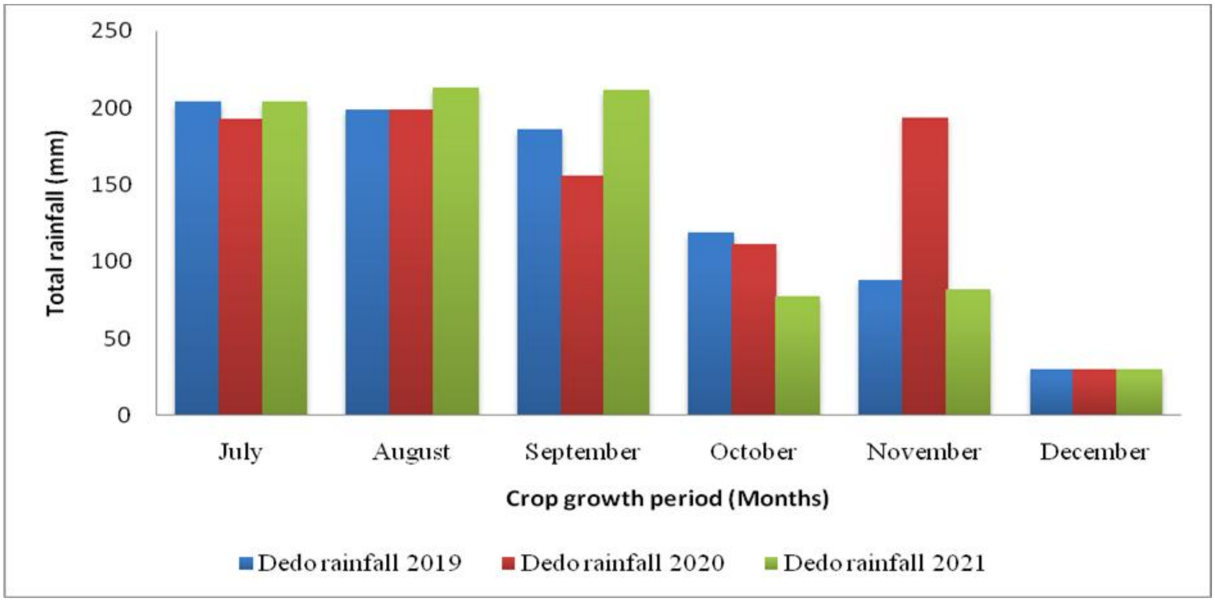

Figure 1. Total rainfall (mm) for the growth period of faba bean at Jimma Dedo district
Source: KNMI Climate data explorer

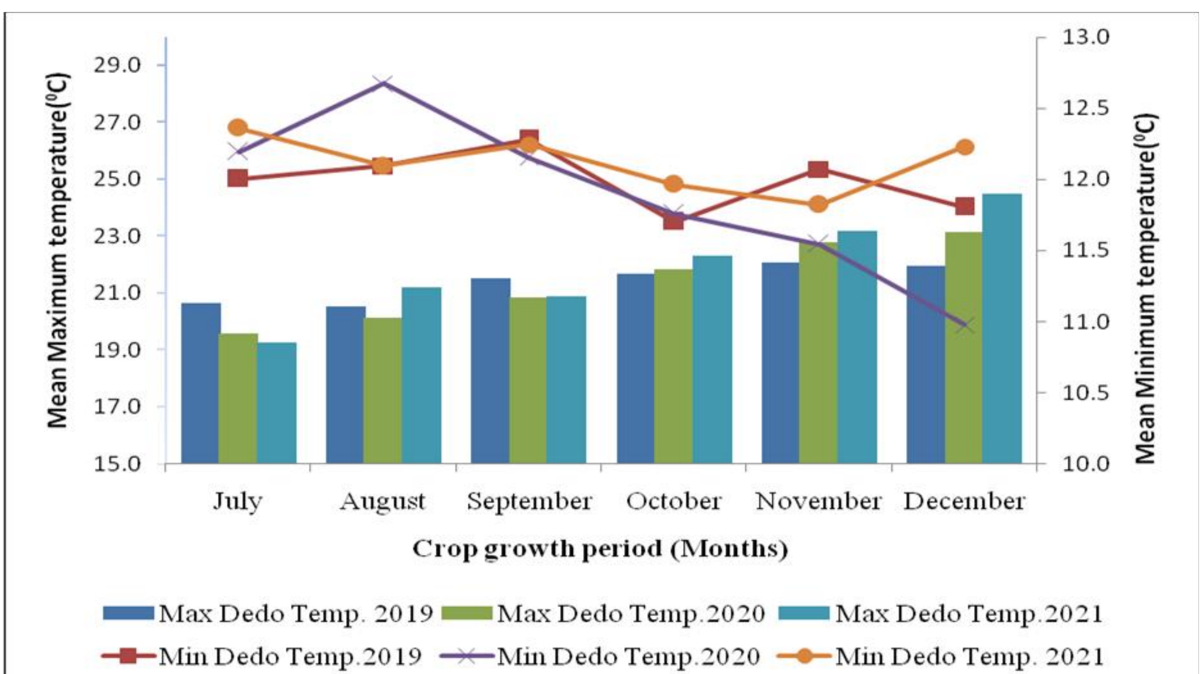

Figure 2. Mean maximum temperature (^{0}C) and mean minimum temperature (^{0}C) for the growth period of Faba bean at Jimma Dedo district
Source: KNMI Climate data explorer

Soil Sampling and Physico-Chemical Properties of the Experimental Sites

A composite soil sample was collected from the whole plot in a zigzag fashion to a depth of 0–30 cm just before sowing for the purposes of determining soil pH, organic carbon, total N, and available P.

The soil pH of the experimental fields was found 4.66(Table 1). As rated by Murphy [17] (1968), the soil at experimental site lies in a very strongly acidic soil class. According to Rajan *et al*. [18], soils with a pH range of 6.5–8.0 are suitable for faba bean production. As a result, the current findings indicated the need for lime application in the experimental area for faba bean production.

The analysis of the soil organic carbon of the experimental fields found 2.16% (Table 1). Tekalign [19] classified soils having an organic carbon content of < 0.50% as very low, 0.5-1.5% as low, 1.5-3.0% as medium/moderate, and > 3.0% as high. Accordingly, the organic carbon content of the experimental soils was found to be medium, indicating the moderate potential of a soil to supply N to plants as it can be used as an index of N availability.

The total N percent in the experimental fields was 0.20 (Table 1). According to Tekalign [19] the total nitrogen content of the experimental soils lies in the moderate range.

The available phosphorous of the experimental soil was 4.50 ppm using the Bray II method and it lies at a very low range [20] (Table 1). Based on these classifications, the available P of the experimental site was found below the P requirement of faba bean (over 20 ppm) [21].

Table 1 Selected Physico-chemical properties of the soil of the experimental sites before planting

Parameter	Value(method of soil analysis)	Rating/soil reaction class
pH (1:2.5 H2O)	4.66 (Soil-water suspension)	Very strongly acidic
Organic carbon (%)	2.16 (Walkley & Black)	Medium
Total nitrogen (%)	0.20 (Kjeldahl)	Moderate
Available phosphorus (ppm)	4.50 (Bray II)	Very low

*Where pH= Hydrogen power; PPM=Parts per Million. Values are the means of duplicated samples.

Treatments and experimental design

The factorial combinations of phosphate fertilizer (23, 46, and 69 kg P_2O_5 ha^{-1}), and plant population densities of 476,190 (30*7cm), 333,333 (30*10cm), 256,410 (30*13cm), 357,143 (40*7cm), 250,000 (40*10cm), 192,308 (40*13cm), 285,714 (50*7cm), 200,000 (50*10cm), 153,846 (50*13cm) plants ha^{-1} were laid out in a randomized complete block design with three replications. A starter amount of Nitrogen (N) fertilizer at the rate of 19 kg N/ha was applied uniformly to all treatments/plots. All the fertilizer was applied at the time of planting. The gross plot size of 4.0 m x 2.4 m (9.6 m^2) was used for all treatments, while the net plot size was made by excluding one outer row from each side. Thus, the net plot size for the respective inter-row spacing of 30, 40, and 50 cm was 4m*1.8m (7.2 m^2), 4m*1.6m (6.4 m^2), and 4m*1.5m (6 m^2), respectively. The number of rows per plot for the 30, 40, and 50 cm inter-row spacing was 8, 6, and 5 rows, respectively, and the number of plants per row for the 7, 10, and 13 cm intra-row spacing was 57, 40, and 31 germinated plants, respectively. The faba bean variety ‘Gora’ was used for this experiment. The germination percentage and seed weight were determined before planting to convert into a seed rate. The seed rate was calculated using the equation stated by Matthews [22] as:

$$\text{Seed rate (kg ha}^{-1}) = \frac{\text{Target plant density (m}^{-2}) \text{ X 100 seed weight (g) X 10}}{\text{Germination percentage (\%) X Establishment percentage (decimal)}}$$

Consequently, to convert plant density into a seed rate, 100 seeds (for our purpose, 93.8 g), germination rates (98%), and 10% field loss (0.90 establishment rate) were used as estimation inputs. All other agronomic practices like two times hand weeding were applied uniformly to all experimental plots in the study area.

Partial Budget Analysis

To assess the costs and benefits associated with different treatments of plant population density (seed rate ha^{-1}) and Phosphorous fertilizer rates, the partial budget technique as described by CIMMYT [23] was applied. Economic analysis was done using the prevailing market prices for inputs at planting and outputs at the time the crop was harvested. All costs and benefits were calculated on the hectare basis of the Ethiopian Birr (ETB). The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment in each years, the field price of faba bean grain (sale price grain yield minus the costs of fertilizer, seed, labor) the gross field benefit (GFB) ha^{-1} (the product of field price of the mean yield for each treatment), the field price of seed rate kg ha^{-1}, phosphorous fertilizer rate and wage rate, the total costs that varied (TCV) which included the sum of field cost of seed, fertilizer and its wage for planting and fertilizer application. The net benefit (NB) was calculated as the difference between the GFB and the TCV. The actual yield was adjusted downward by 10% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. There were expected plant population density, timely labor availability and better management (e.g. Weed control, rainfall) under the experimental conditions [23]. The dominance analysis procedure as detailed in CIMMYT [23] was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest cost. For each pair of rank treatments, the percent marginal rate of return (MRR) was calculated. The MRR (%) between any pair of undominated treatments was the return per unit of investment in fertilizer. To obtain an estimate of these returns the MRR (%) was calculated as changes in net benefit divided by changes in cost. Thus, the MRR of 100% was used indicate for every one ETB expended there is a return of one ETB for a given variable input.

Sensitivity analysis for different interventions was also carried out to test the recommendation made for its ability to withstand price changes. Sensitivity analysis simply implied redoing marginal analysis with the alternative prices. Through sensitivity analysis, the maximum acceptable field price of input was calculated with the minimum rate of return as described by Shah *et al.* [24].

Crop data collection and statistical analysis

The number of pods per plant was measured from 10 randomly selected plants from the central rows of each plot, while grain yield was measured from the central rows of each plot. Data collected was subjected to the analysis of variance (ANOVA) following the statistical procedure stated by Gomez and Gomez [25] for all collected data was computed using SAS software version 9.3. The significance of differences between samples was separated using the least significance difference (LSD) at a 5% level of significance.

Results and Discussion

The analysis of variance indicated that the P fertilizer rates and plant population densities didn’t show significant ($P>0.05$) interaction effect on plant height, pods per plant, seed per pod, aboveground biomass and harvest index (Table 2). But, highly significant ($P\leq0.01$) interaction effect was observed for grain yield. The plant population density showed non- significant ($P>0.05$) effect on plant height, pods per plant, seed per pod, and harvest index, but significant ($P\leq0.05$) effect was observed for grain yield and above ground biomass (Table 2). On other hand concerning P fertilizer rates; plant height, seeds per pod and grain yield was not significantly

(P>0.05) affected by P fertilizer rates, where as pods per plant and harvest index significantly (P≤0.05) and above ground biomass was highly significantly (P≤0.01) influenced by P fertilizer rates. Year difference were showed highly significant (P≤0.01) effect for all parameters collected except for seeds per pod which was significantly (P≤0.05) affected (Table 2).

Table 2 Mean square from combined analysis of the effects of plant population densities and Phosphorous fertilizer rates on growth, yield attributes and yield of Faba bean during 2019-2021 cropping seasons at Dedo district, Jimma zone Southwestern Ethiopia

Parameter	Mean square for source of variation								
	Year (2)	PPD (8)	P rate (2)	Rep (2)	PPD x P rate (16)	Year x PPD (16)	Year x P rate (4)	Year * PPD*P rate (32)	MS of Error (52)
Plant height (cm)	3229.4**	208.495^{ns}	267.177^{ns}	8016.0**	303.18^{ns}	235.66^{ns}	373.19^{ns}	193.51^{ns}	267.70
Pods per plant	111.542**	6.0068^{ns}	12.878*	3.113^{ns}	5.507^{ns}	2.612^{ns}	4.3139^{ns}	3.2532^{ns}	4.59
Seeds per Pod	0.322*	0.098^{ns}	0.108^{ns}	0.404**	0.094^{ns}	0.061^{ns}	0.032^{ns}	0.085^{ns}	0.087
Grain yield (kg ha^{-1})	48.434**	1.667*	0.426^{ns}	12.476**	1.794**	0.906^{ns}	0.572^{ns}	0.627^{ns}	0.72
AGB (t ha^{-1})	214.763**	13.937*	28.776**	45.021**	6.443^{ns}	9.599^{ns}	4.366^{ns}	2.565^{ns}	6.41
Harvest index	2387.43**	58.436^{ns}	185.5998*	135.30^{ns}	59.274^{ns}	34.428^{ns}	31.077^{ns}	50.016^{ns}	57.42

Numbers in parenthesis = Degrees of freedom; NS=Not significant difference; ***=** Significant (P ≤ 0.05) difference; ** = Highly significant (p≤0.01) difference; AGB= Above ground biomass; PPD=Plant population density; P=Phosphorous; Rep=Replication; MS=Mean square; ha = Hectare

Number of Pods per plant

A higher number of pods per plant (10.9) were recorded in the third year (2021) which was statically similar with first year (2019), where as the lowest (8.6) number of pods per plant were obtained during second year (2020) (Figure 3).This is probably related to the rainfall and temperature effect. As seen in Fig. 1 and 2, the higher rainfall in the first and third year during the podding stage (September to October) and the constantly higher temperatures in the third year beginning from October to December might have resulted in higher pod numbers than in the second year. As described by Yucel [26], this trait is greatly influenced by environmental factors such as temperature and precipitation.

The significant higher number of pods per plant (10.2) was recorded from P fertilizer rate of 69 kg P_2O_5 ha^{-1} where as the lowest number pod per plant (9.5) was recorded from the lowest P fertilizer rate of 23 kg P_2O_5 ha^{-1}(Table 3).The number of pods per plant linearly increased by 7.4% as P_2O_5 fertilizer increased from 23 kg ha^{-1} to 69 kg ha^{-1}. In line with this result, Ghizaw *et al*. [27] described a linear increase in the number of pods per plant as P_2O_5 fertilizer increased from 0 kg ha^{-1} to 92 kg ha^{-1} at different locations, while Agegnehu & Tsige [10] reported a linear increase in the number of pods per plant as P_2O_5 fertilizer increased from 0 kg ha^{-1} to 120 kg ha^{-1} in acid prone areas.

Table 3. Main effect of year, plant population density and phosphorus on number of pods per plant, number of seeds per pod and grain yield of faba bean at Jimma Dedo woreda

Factors	NPPP	NSPP	GY (tha^{-1})	PH(cm)	HI	AGB($t\ ha^{-1}$)
P_2O_5 (kg/ha)						
23	9.5^{b}	2.7	4.7	149.1	37.7^{a}	11.04^{b}
46	10.0^{ab}	2.8	4.9	146.8	35.2^{b}	11.75^{ab}
69	10.2^{a}	2.8	4.9	150.4	35.0^{b}	12.22^{a}
LSD	0.67	0.09	0.26	5.08	2.35	0.786
F test	*	ns	ns	ns	*	**
Plant population density ha^{-1}						
476,190 (30*7cm)	9.3	2.7	3.95^{bcd}	149.7	33.6	12.15^{ab}
333,333 (30*10cm)	9.4	2.7	4.15^{a-d}	146.9	34.9	12.08^{abc}
256,410 (30*13cm)	9.7	2.8	3.81^{d}	153.4	34.3	11.37^{a-d}
357,143 (40*7cm)	9.8	2.7	4.37^{abc}	149.7	36.4	12.72^{a}
250,000 (40*10cm)	9.8	2.7	4.40^{ab}	149.9	36.8	12.09^{abc}
192,308 (40*13cm)	10.3	2.8	3.91^{cd}	144.2	37.1	10.70^{d}
285,714 (50*7cm)	9.9	2.8	4.47^{a}	149.2	37.3	12.11^{abc}
200,000 (50*10cm)	10.0	2.8	3.88^{d}	145.6	35.5	11.01^{bcd}
153,846 (50*13cm)	10.8	2.9	4.04^{a-d}	150.5	37.8	10.79^{cd}
Mean	9.91	2.8	4.11	148.8	35.97	11.67
LSD	1.15	0.16	0.46	8.8	4.07	1.36
F test	ns	ns	*	ns	ns	*
CV (%)	21.6	10.7	20.6	11.0	21	21.1
P_2O_5*PPD	ns	ns	**	ns	ns	ns

**= significant at 1% level of significance, ns = Not significant, CV=coefficient of variation; LSD= Least significant deference; NPPP= Number of pods per plant; NSPP= Number of seeds per pod; GY= Grain yield; PH=Plant height; PPD=Plant population density

Table 4. Two-way interaction effects of phosphorus with Plant population density on the grain yield of faba bean combined over years at Jimma Dedo woreda

Plant population density ha^{-1}	Grain yield ($t\ ha^{-1}$)		
	P_2O_5 (kg/ha)		
	23	46	69
476,190 (30*7cm)	3.96^{a-d}	3.76^{a-d}	4.14^{a-d}
333,333 (30*10cm)	3.82^{a-d}	4.48^{ab}	4.15^{a-d}
256,410 (30*13cm)	3.58^{bcd}	3.54^{bcd}	4.33^{ab}
357,143 (40*7cm)	4.18^{a-d}	4.50^{ab}	4.42^{ab}
250,000 (40*10cm)	4.66^{a}	4.30^{ab}	4.24^{abc}
192,308 (40*13cm)	4.46^{ab}	3.13^{d}	4.14^{a-d}
285,714 (50*7cm)	4.49^{ab}	4.22^{abc}	4.71^{a}
200,000 (50*10cm)	3.23^{cd}	4.79^{a}	3.61^{bcd}
153,846 (50*13cm)	4.19^{abc}	3.94^{a-d}	4.00^{a-d}
Mean	4.11		
LSD	1.05		
CV (%)	20.6		

Number of seeds per pod

In similar to the number of pods per plant, the highest number of seeds per pod (2.83) was obtained in the third year (2021) where as the lowest number of seeds per pod (2.71) was recorded from second year (2020) (Figure 3). Though, the higher rainfall in the third year and the higher temperatures in the third year beginning from October to December might have resulted in higher number of seeds per pod than in the second year. In agreement with this result, Al-Rifaee *et al*. [28] obtained a higher number of seeds per pod for the year that had a fair distribution of rainfall throughout the growth period. Number of seeds per pod was not significantly affected by any of the main effects of plant population density and P fertilizer rates or by any of their interactions (Table 3).

Grain yield

The highest grain yield (4.57 t ha^{-1}) was recorded in the second year (2020), where as the lowest (3.22 t ha^{-1}) was obtained during third year (2021) (Figure 3), this is probably due to the good distribution and highest rainfall during the growth period of 2020 (Fig. 1). The presence of considerable and unpredictable year-on-year variation in the seed yield of faba bean, despite adequate control of pests and diseases, is well reported by López-Bellido *et al*. [13]. The same authors find that yield shows a greater response to yearly environmental conditions such as rainfall and maximum daily temperatures.

Numerically the significant highest grain yield of 4.79 t ha^{-1} was recorded from interaction effect of plant population density of 200,000 plants ha^{-1} (50*10cm) with P fertilizer rate of 46 kg P_2O_5 ha^{-1} where as the lowest grain yield of 3.23 t ha^{-1} was obtained from interaction effect of plant population density of 200,000(50*10cm) plants ha^{-1} with P fertilizer rate of 23 kg P_2O_5 ha^{-1} (Table 4). Grain yield increased by 48.3% with increasing of P fertilizer rate at 46 kg P_2O_5 ha^{-1} compared with the lowest P fertilizer rate of 23 kg P_2O_5 ha^{-1} with plant population density of 200,000(50*10cm) plants ha^{-1}. Since there was interaction between plant population density and P fertilizer rates, the economic analysis could be performed to select the feasible plant population density and P fertilizer rate. In line with this result, Ibrahim [9] reported the presence of interaction between plant spacing and fertilizer application in faba bean. In contrast to the present fertilizer rate, Tsige *et al*. [29] suggested the use of 92 kg P_2O_5 ha^{-1} in combination with 23 kg N ha^{-1} and 60 kg K_2O ha^{-1} in the acidic soils of the Wolaita Zone, southern Ethiopia.

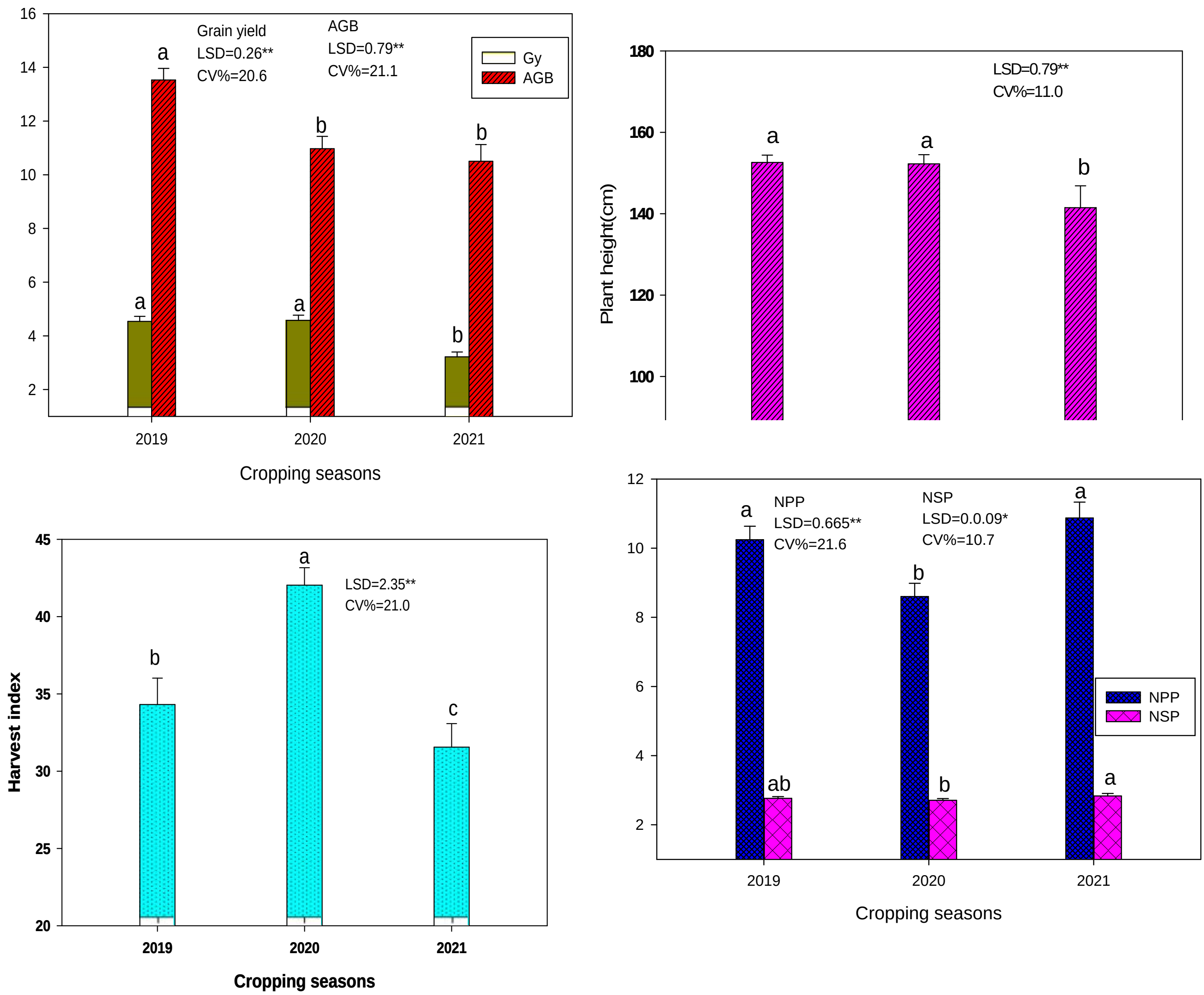

Figure 3 Over cropping seasons effect of plant population density and P fertilizer rates on growth, yield and yield related parameters of faba bean

Above Ground Biomass

The highest above ground biomass (13.53 t ha^{-1}) was recorded in the first year (2019), where as the lowest (10.50 t ha^{-1}) was obtained during third year (2021) (Figure 3), this is probably due to the higher rainfall in the first year during the podding stage (September to October) and highest pod formation in relation to higher grain yield (Fig. 1 and 2).

Numerically the significant highest above ground biomass of 12.22 t ha^{-1} was recorded from P fertilizer rate of 69 kg P_2O_5 ha^{-1} which was statistically at par with 46 kg P_2O_5 ha^{-1}, while the lowest above ground biomass of 11.04 t ha^{-1} was obtained from the lowest P fertilizer rate of 23 kg P_2O_5 ha^{-1}(Table 3). The above ground biomass was increased by 10.7% with increasing of P fertilizer rate of 69 kg P_2O_5 ha^{-1} compared with the lowest P fertilizer rate of 23 kg P_2O_5 ha^{-1}. Total aboveground biomass and seed yield of faba bean significantly responded to P fertilizer application [30]. Concerning plant population density the significant highest above ground biomass of 12.72 t $ha^{-1}$was recorded from plant population density of

357,143(40*7cm) plants ha^{-1} while the lowest (10.7 t ha^{-1}) was obtained from plant population density of 192,308(40*13cm) plants ha^{-1} (Table 3). The results indicated that as plant population density increased the above ground biomass also numerically increased proportionally but after certain level, it declines and vice versa. Faba bean plants have a capacity to produce many stems and a large amount of biomass under abundant space [31] (Matthews and Marcellos, 2003).

Correlation analysis

The relationship between grain yield with growth parameters and yield related traits was presented in (Figure 4). The results were showed that grain yield was positively and highly significantly ($P<0.01$) correlated with above ground biomass (R^2=0.46). Whereas it was negatively and significantly ($P<0.05$) correlated with number of seeds per pod (R^2=0.17). This is due to as plant population densities increased number of seeds per pod was decreased and plant population density had great impact on number of seeds per pod to negatively correlate with grain yield. While it was not significantly ($P>0.05$) correlated with number of pods per plant (R^2=0.03) and plant height (R^2=0.04).

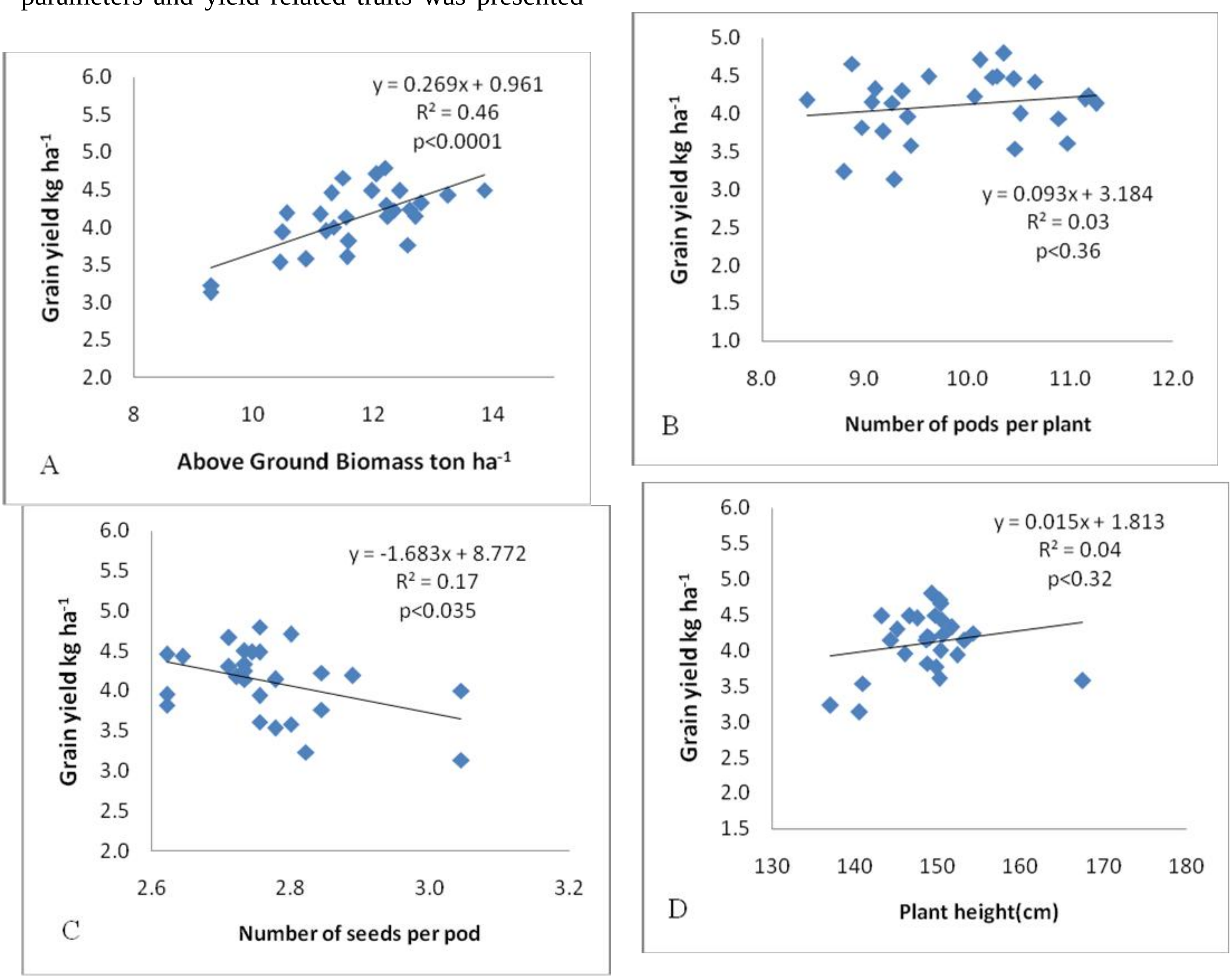

Figure 4 Relationships between grain yield with above ground biomass (A), number of pods per plant (B), number of seed per pod(C) and plant height (D) at Dedo district of Jimma zone during 2019-2021 main cropping seasons

Partial budget analysis

Economic analysis was performed using partial budget analysis following the procedure described by CIMMYT [23] in which prevailing market prices for inputs at planting and for outputs at harvesting were used. All costs and benefits were calculated on hectare basis in Ethiopian Birr (ETB). The grain yield was adjusted by 10% for management difference. The total costs of fertilizers (NPS = 21.5 ETB kg^{-1}) were calculated based on store sale average price of Dedo district Cooperative and sale of grain fababean at open market average price (33 ETB kg^{-1}). The partial budget analysis revealed that the highest net benefit of 135,444 ETB ha^{-1} was obtained from interaction effect of 46 P_2O_5 kg ha^{-1} and plant population density of 200,000 plants ha^{-1} (50*10cm) (Table 5).The highest marginal rate of return (MRR) of 830.7% and 671.3% was obtained from interaction effect of 46 P_2O_5 kg ha^{-1} with plant population density of 192,308 plants ha^{-1} and 23 P_2O_5 kg ha^{-1} with plant population density of 200,000 plants ha^{-1} respectively (Table 6).

Table 5.Partial budget for the interaction effects of P fertilizer and plant population density of Faba bean grain yield at Jimma Dedo woreda during 2019-2021 main cropping seasons

Phosphorous (P_2O_5) rate (kg ha^{-1})	Plant density ha^{-1} (Inter * Intra row spacing)	Grain yield (t ha^{-1})	Adj. Grain Yield (t ha^{-1})	GFB (ETB ha^{-1})	TVC (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	Dominance
23	153,846 (50*13cm)	4.19	3.77	124493.15	4833.15	119660	--
46	153,846 (50*13cm)	3.94	3.54	116911.81	5606.81	111305	D
23	192,308 (40*13cm)	4.46	4.01	132398.55	5682.55	126716	UD
23	200,000 (50*10cm)	3.23	2.91	95985.79	5943.79	90042	D
69	153,846 (50*13cm)	4.00	3.60	118859.68	6702.68	112157	D
46	192,308 (40*13cm)	3.13	2.82	93105.58	6820.58	86285	D
46	256,410 (30*13cm)	3.54	3.18	105041.65	6829.65	98212	D
46	200,000 (50*10cm)	4.80	4.32	142426.78	6982.78	135444	UD
23	250,000 (40*10cm)	4.66	4.19	138432.43	7096.43	131336	D
23	256,410 (30*13cm)	3.58	3.22	106321.11	7180.11	99141	D
69	192,308 (40*13cm)	4.14	3.72	122910.98	7558.98	115352	D
23	285,714 (50*7cm)	4.49	4.04	133222.19	7598.19	125624	D
69	200,000 (50*10cm)	3.61	3.25	107204.57	7736.57	99468	D
46	250,000 (40*10cm)	4.30	3.87	127709.70	7995.70	119714	D
46	285,714 (50*7cm)	4.23	3.80	125487.28	8812.28	116675	D
23	333,333 (30*10cm)	3.82	3.44	113486.88	8894.88	104592	D
69	256,410 (30*13cm)	4.33	3.89	128509.66	8953.66	119556	D
69	250,000 (40*10cm)	4.24	3.82	126029.60	9027.60	117002	D
23	357,143 (40*7cm)	4.18	3.76	124124.30	9281.30	114843	D
69	285,714 (50*7cm)	4.71	4.24	139798.79	9500.79	130298	D
46	333,333 (30*10cm)	4.48	4.04	133167.84	9903.84	123264	D
46	357,143 (40*7cm)	4.50	4.05	133502.22	10085.2	123417	D
69	333,333 (30*10cm)	4.15	3.73	123213.95	10680.9	112533	D
69	357,143 (40*7cm)	4.42	3.98	131397.46	11286.5	120111	D

23	476,190 (30*7cm)	3.96	3.56	117464.69	11613.7	105851	D
46	476,190 (30*7cm)	3.76	3.39	111790.96	12810.0	98981	D
69	476,190 (30*7cm)	4.14	3.73	123022.81	13685.8	109337	D

*GFB = Gross field benefit; TVC = Total variable cost; D=Dominated treatments; UD=Un-Dominated treatments; ETB = Ethiopian Birr

Table 6. Partial budget with estimated MRR (%) for the interaction effects of P fertilizer and plant population density of Faba bean grain yield at Jimma Dedo district during 2019-2021 main cropping seasons

Phosphorous(P_2O_5) rate (kg ha^{-1})	Plant density ha^{-1} (Inter * Intra row spacing)	TVC (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	MRR (%)
23	153,846 (50*13cm)	4,833.15	119,660	---
23	192,308 (40*13cm)	5,682.55	126,716	830.7
46	200,000 (50*10cm)	6,982.78	135,444	671.3

*TVC = Total variable cost; MRR=Marginal Rate of Return

It is well known that market prices are ever changing and as such a recalculation of the partial budget using a set of likely future prices *i.e.*, sensitivity analysis, was essential to identify treatments which may likely remain stable and sustain satisfactory returns for farmers despite price variation of 15%. The price changes are not sensitive under market conditions prevailing at Jimma (Dedo district) which were above the minimum acceptable MRR of 100% (614.0% and 496.2%) from interaction effect of 46 P_2O_5 kg ha^{-1} with plant population density of 192,308 plants ha^{-1} and 23 P_2O_5 kg ha^{-1} with plant population density of 200,000 plants ha^{-1} respectively (Table 7).

Table 7 Sensitivity analysis of faba bean production based on a 15% rise in total cost and price of gross field benefit fall at Jimma Dedo district during 2019-2021 main cropping seasons

Phosphorous (P_2O_5) rate (kg ha^{-1})	Plant density ha^{-1} (Inter * Intra row spacing)	TVC (ETB ha^{-1})	Net Benefit (ETB ha^{-1})	MRR (%)
23	153,846 (50*13cm)	5,558.12	101,711.0	---
23	192,308 (40*13cm)	6,534.94	107,708.6	614.0
46	200,000 (50*10cm)	8,030.20	115,127.4	496.2

*TVC = Total variable cost; MRR=Marginal Rate of Return

Summary and Conclusion

The study was conducted to determine the response of fababean to plant population density and phosphorous fertilizer rate on growth parameters, yield and yield components at Jimma Dedo district South Western Ethiopia during 2019-2021 main cropping seasons. During 2019 main cropping season the highest plant height, above ground biomass and grain yield was recorded than during 2020 and 2021 main cropping seasons. While highest number of pods per plant and seeds per pod was recorded during main cropping season of 2021. Whereas the highest harvest index was recorded during 2020 main cropping season. There was no interaction effect observed among plant population densities and P fertilizer rates for plant height, number of pods per plant, number of seeds per pod, above ground biomass and harvest index except for grain yield. The significant highest grain yield of 4.79t ha^{-1} was recorded from interaction effect of plant population density of 200,000 plants ha^{-1} (50*10cm) with P fertilizer rate of 46 kg P_2O_5 ha^{-1} with highest net benefit of 135,444 ETB ha^{-1} and Marginal rate of return of 671%. Thus the fertilizer rate of 46 kg P_2O_5 ha^{-1} and N at the rate of 19 kg ha^{-1} together with plant population density of 200,000 plants ha^{-1} (10 cm intra-row-and 50 cm inter-row spacing equivalent to 20 plants per square meter) was found to be optimum for the study areas and similar agro-ecologies.

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References

[1] Abebe Zerihun and Tolera Abera. 2014. Yield Response of Faba bean to Fertilizer Rate, Rhizobium Inoculation and Lime Rate at Gedo Highland, Western Ethiopia. *Global Journal of Crop, Soil Science and Plant Breeding*, 2 (1): 134-139.

[2] Yirga W, Kiros H, Mitiku Haileb. 2012. Effect of Zinc and Phosphorus fertilizer application on nodulation and nutrient concentration of faba bean (*Vicia faba L.*) grown in calcric Cambisols of semiarid Northern Ethiopia. Journal of Soil Science and Environmental Management 3(12): 320-326.

[3] CSA (Central Statistical Agency). 2021. The Federal Democratic Republic of Ethiopia Central Statistical Agency Report on Area and Production of Major Crops. *Statistical Bulletin*, vol. 1, no. *590*.

[4] Negasa G., B. Bedadi, and T. Abera. 2019. Influence of Phosphorus Fertilizer Rates on Yield and Yield Components of Faba Bean (*Vicia faba* L.) Varieties in Lemu Bilbilo District of Arsi Zone, Southeastern Ethiopia. *International Journal of Plant & Soil Science*, *November*, vol. 28, no. 3, pp. 1–11.

[5] Adak M. S., and M. Kibritci. 2016. Effect of nitrogen and phosphorus levels on nodulation and yield components in faba bean (*Vicia faba* L.). *Legume Research*, vol. 39, no. 6, pp. 991–994.

[6] Sangoi L. 2000. Understanding Plant Density Effects on Maize Growth and Development: An Important Issue to Maximize Grain Yield. Ciência *Rural*, vol. 31, no. 1, pp. 159–168.

[7] Smitchger J. and N. F. Weeden. 2018. The Ideotype for Seed Size: A Model Examining the Relationship between Seed Size and Actual Yield in Pea. *Hindawi*, *International Journal of Agronomy*, vol. 2018, pp. 1-7, Article ID 9658707.

[8] Olle M. 2018. Suitable Sowing Rate for Peas and Beans - A Review. *JOJ Horticulture and Arboriculture*, vol 1, no. 1, pp. 25–28.

[9] Ibrahim M. M. 2009. Effect of Plant Spacing and Phosphorus Fertilization on Growth and Productivity of Faba Bean. *Journal of Plant Production*, vol. 34, no. 2, pp. 1183–1196.

[10] Agegnehu G., A. Fikre, and A. Tadesse. 2006. Cropping Systems, Soil Fertility and Crop Management Research on Cool-season Food Legumes in the Central Highlands of Ethiopia: A Review. In *Proceedings of the Workshop on Food and Forage Legumes*, K. Ali, G. Keneni, S. Ahmed, R. Malhotra, S. Beniwal, K. Makkouk, and M. H. Halila (Eds.), Food and Forage Legumes of Ethiopia: Progress and Prospects. 22-26 September 2003, Addis Ababa, Ethiopia, pp. 135–145.

[11] Alemayehu D., and D. Shumi. 2018. Response of Faba Bean (*Vicia faba* L.) to Phosphorus Nutrient Application in Bore. *Agricultural Research & Technology: Open Access Journal*. vol. 17, no. 4, pp. 001-008.

[12] Getu, A., Gashu, K., Mengie, Y., Agumas, B., Abewa, A., Alemayehu, A. 2020. Optimization of P and K fertilizer recommendation for faba bean in Ethiopia: The case for Sekela District. *World Scientific News*, no. 142, pp. 169–179.

[13] López-Bellido F.J., L. López-Bellido, and R. J. López-Bellido. 2005. Competition, growth and yield of faba bean (*Vicia faba* L.). *European Journal of Agronomy*, vol. 23, pp. 359 – 378.

[14] Dobocha D., and D. Bekele. 2021. Faba Bean Agronomic and Crop Physiology Research in Ethiopia," *Legumes*, vol. 1.

[15] Gezahegn A. M., K. Tesfaye, J. J. Sharma, and M. D. Belel. 2016. Determination of optimum plant density for faba bean (Vicia faba L.) on *vertisols* at Haramaya, Eastern Ethiopia. *Cogent Food and Agriculture*, vol. 2, no. 1, pp.

[16] Tamrat M. 2021. Advancements in Crop and Soil Management Practices of Faba Bean in Ethiopia: A Review. *African Journal of Basic & Applied Sciences*, vol. 13, no. 4, pp. 29-40.

[17] Murphy, H.F. 1968. A report on fertility status and other data on some soils of Ethiopia. Collage of Agriculture HSIU. Experimental Station Bulletin No. 44, Collage of Agriculture: 551p.

[18] Rajan, K., Singh A.K. and Pandey, A.K. 2012. Faba bean soils and their management for higher productivity. pp. 205-212. *In*: Singh and Bhatt (eds.), *Faba Bean (Vicia faba L.): A potential leguminous crop of India*. ICAR, RC for ER, Patna.

[19] Tekalign Tadese. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.

[20] Bray, R.H., Kurz, L.T. 1945. Determination of total, organic and available forms of phosphorus in soil. Soil Sci. 59: 39-45, Ankerman, D., Large. (SD). Agronomy handbook, soil and plant analysis, A and L. Agricultural Laboratories, Memphis, USA.

[21] Agegnehu G., and A. Tsige. 2006. The role of phosphorus fertilization on growth and yield of faba bean on acidic nitisol of central highland of Ethiopia. *Ethiopian Journal of Science*, vol. 29, no. 2, pp. 177–182.

[22] Matthews P. 2005. Germination testing and seed rate calculation. *Pulse Point 20, NSW*, Department of Primary Industries, Temora.

[23] CIMMYT. 1988. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. Mexico, D.F.79p.

[24] Shah STH, Zamir MSI, Waseem M, Ali A, Tahir M, Khalid WB. 2009. Growth and yield response of maize to organic and inorganic sources of nitrogen. Pakistan Journal of life science **7**:108-111.

[25] Gomez, K. A. and Gomez, A. A., 1984. Statistical Procedures for Agricultural Research. 2nd ed. John Wiley and Sons. New York.

[26] Yucel D. O. 2013. Optimal intra-row spacing for production of local faba bean (Vicia faba L. major) cultivars in the Mediterranean conditions. *Pakistan Journal of Botany*, vol. 45, no. 6, pp. 1933–1938.

[27] Ghizaw A., T. Mamo, Z. Yilma, A. Molla, and Y. Ashagre. 1999. Nitrogen and phosphorus effects on faba bean yield and some yield components. *Journal of Agronomy and Crop Science*, vol. 182, no. 3, pp. 167–174.

[28] Al- Rifaee M., M.A. Turk, and A. R. M. Tawaha. 2004. Effect of Seed Size and Plant Population Density on Yield and Yield Components of Local Faba Bean *(Vicia faba* L. Major). *International journal of agriculture & biology*, vol. 6, no. 2, pp. 294-299.

[29] Tsige B. A., N. Dechassa, T. Tana, F. Laekemariam, and Y. Alemayehu. 2022. Effect of Mineral Nitrogen, Phosphorus, and Potassium Fertilizers on the Productivity of Faba Bean (Vicia faba L.) in Acidic Soils of Wolaita Zone, Southern Ethiopia. *Hindawi, International Journal of Agronomy*, vol. 2022, pp. 1-18, Article ID 2232961.

[30] Getachew, A. and Rezene, F. 2006. Response of Faba Bean to Phosphate Fertilizer and Weed Control on Nitisols of Ethiopian Highlands. *Australian Journal of Agricultural Research*, *20*(3), pp.265-268.
[31] Matthews, P. and H. Marcellos. 2003. Faba bean. Research Agronomist, Tamworth. Auatralia, 2: 42-47.

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