Effects of bio-fertiliser and inter-row spacing on yield and yield components of faba bean (*Vicia faba* L.) in south western Ethiopia

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Fertiliser application and planting densities are among the main factors which affect the growth, development and grain productivity per unit area for faba bean. The current trial was done to determine the effect of bio-fertiliser and inter-row spacing on the yield and yield related traits of faba bean (*Vicia faba* L.) in south western Ethiopia. Treatments consisted of four rates of rhizobium strain bio-fertiliser (0, 0.25, 0.5 and 0.75 kg/ha) and three inter-row spacings (30, 40, and 50 cm), were laid out as a randomised complete block replicated three times. Analysis of variance showed that the main and interaction effects of rhizobium strain bio-fertiliser and inter-row spacing were significant for days to 50% flowering, number of effective nodules, leaf area index and grain yield. The main effects of rhizobium inoculation and inter-row spacing were significant for plant height, number of leaves per plant, pods per plant, dry weight, above ground dry biomass yield and harvest index. The highest grain yield (2540 kg/ha) was obtained from the application of 0.75 kg/ha bio-fertiliser and 50 cm inter-row spacing while the lowest (1083 kg ha) was obtained from the control of no bio-fertiliser and the narrowest inter-row spacing (30 cm). Generally, significantly higher yields were obtained from the application of the highest rate (0.75 kg/ha) of bio-fertiliser and the widest (50 cm) inter-row spacing. Maximum net return, (ETB53, 850 or US$1843/ha) was obtained by inoculation with a bio-fertiliser rate of 0.75 kg ha and an inter-row spacing of 50 cm. Therefore, inoculation of bio-fertiliser at rate of 0.75 kg ha with inter-row spacing of 50 cm, was found to optimise the yield of faba bean in south western Ethiopia.

Keywords***:*** Bio-fertiliser, faba bean, inter-row space, pulses, rhizobium.

The word pulse as used by the Food and Agricultural Organization (FAO 2019) refers to crops grown for the dry seed. Grain legumes are important due to their high protein and essential amino acid content. Faba bean (*Vicia faba* L.) is the fourth most important pulse crop in the world based on its area under production (Jungers et al. 2019). Faba bean is used both as dry seeds and a green vegetable. Its products are a rich source of high quality protein in the human diet, while its dry seeds, green haulm and dry straw are used as animal feeds (Woomer et al. 2012).

Ethiopia is the second largest faba bean producer in the world and shares 7.0% of world, and 40.2% of African faba bean production (Tolessa et al. 2015). Faba bean is produced in most parts of Ethiopia. South western Ethiopia produces 14.1% of the faba bean grown in the country (Birhanu et al. 2018). The crop has been used by growers and consumers as a source of food, feed, and income. Faba bean also plays an important role in soil nutrient management and is a major contributor to all aspects of Ethiopian life (Woomer et al. 2012; Desta et al. 2015).

In Ethiopia, faba bean yields of small-holder farmers are less than 2100 kg/ha (CSA 2018). Several factors, such as soil infertility, unsuitable stand density, inappropriate planting time, poor farm practices, and pests and diseases all affect the productivity of faba

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bean (Under Newly 2011). According to different studies carried out in Ethiopia, different plant spacings and soil fertility affect grain yield and yield characteristics of faba bean (Wondimu et al. 2019; Addisu and Tadele 2021).

The use of bio-fertiliser is being considered as an alternative approach to reduce the use of mineral N-fertiliser (Herridg et al. 2008). Bio-fertiliser involves the use of microorganisms, which might readily and effectively change biological material into simple composites, so that they are easily taken up by the plants. Planting population has been shown to be the main influence in determining crop yield (Matthews et al. 2008). The ideal plant population per unit area permits faba bean crops to efficiently use fertilisers and obtain maximum production (Sharma et al. 2000). However, differences in crop growth patterns, planting time and the weather patterns also affect yield (Matthews et al. 2008; Under Newly 2011). Hence, this study was aimed at evaluating the individual and combined effect of rhizobium inoculation and inter-row spacing on grain yield and yield components of faba bean at Kaffa Zone, south western Ethiopia.

Materials and methods

Description of the experimental site

The field trial was done in the 2019 main cropping season at Bonga Agriculture Research Center.

The site is 476 km from Addis Ababa at 7° 17' N and 36° 43' E. The altitude of the trial site is 2500 masl. The rainfall pattern is bimodal in distribution. The maximum rainfall in the research area during the 2019 crop growing season was 274.6 mm in July and the minimum was 167.3 mm in October. The maximum temperature during the crop growing season was 26.7ºC in October and the minimum was 9.9ºC in August (Wushwush Meteorology Station 2019).

Experimental materials

The rhizobium strain HUFBR-15 bio-fertiliser was used because of its wide adaptation in highland soil conditions and high rainfall areas. The inoculums were produced by mixing culture liquid medium containing 108 viable rhizobia/ml with well decomposed filter mud. This production was undertaken at the bio-fertiliser research and production laboratory of Melkassa Agricultural Research Center, Ethiopia. The faba bean variety Tumsa was used in the experiment because of its high yielding ability and appreciable agronomic performance throughout the country. The variety matures in 90 – 120 days depending on the cultivar and climatic conditions. The average yield obtained by different researchers and nationally accepted from this variety is 1520 kg/ha (CSA 2011).

Experimental procedure and crop management

The experimental field was ploughed three times using a tractor and the plots leveled manually. Faba bean seeds were washed with clean water, air dried, and then soaked with the rhizobium strain for 30 minutes before planting. Seeds were planted manually at the recommended seeding depth of 5 cm.

Soil sampling and analysis

Soil samples were taken at depths of 0 – 30cm, using a zigzag method across the experimental site. The composite soil sample was analysed for soil texture, soil pH, organic carbon (OC), total nitrogen (N), available phosphorus (P) and cation exchange capacity (CEC) using standard laboratory procedures. The soil analysis was done at the Jimma Agricultural Research Institute soil and plant tissue laboratory. N was tested in the laboratory using the Kjeldahl technique and P was estimated based using the Bray II technique. Soil pH (1:2:5) was estimated by the soil-water suspension technique using a pH meter. Soil CEC was determined by the ethanol 95% extraction technique. The analysis results showed that the soil consists of 50% sand, 44% clay and 6% silt. The soil textural class is sandy clay. Soil pH (6.00) is slightly acidic, available P **(**65.76 ppm) is high; OC (2.64%) is low, total N (0.39%) very high and CEC (20.64 meq/100 gm) medium.

Experimental design and treatment arrangements

The experiment was laid out in a randomised complete with three replications and 12 treatments. The treatments were a factorial combination of four rates of bio-fertiliser (0, 0.25, 0.5 and 0.75 kg/ha) and three inter-row spacings (30, 40 and 50 cm). The rhizobium strain was soaked in water for 30 minutes at the appropriate rate for the treatments. Prior to innoculation of the faba bean seeds, 10% sugar solution was added as an adhesive agent and the water was slightly boiled to support adhesion to the seeds.

Data collected

Data were collected on crop phenological characters, growth parameters and yield parameters. Phenological data were collected on days to 50% emergence and flowering. Growth parameters measured were plant height, number of effective nodules per plant, number of leaves per plant, dry weight of nodules and leaf area index. Yield parameters measured were number of seeds per pod, number of pods per plant, above ground dry bio-mass yield, weight of 100 seeds, grain yield and harvest index. Grain yield was recorded from the net plot area of each plot, after the grains were sun dried at room temperature and trashed.

Data analysis

Data were summarised and subjected to the analysis of variance (ANOVA**)** procedure of factorial combination for randomised complete block design using the SAS software (SAS 2002). Least significant differences tests were performed at P = 0.05 to separate means. Correlation analysis was done between all parameters.

Partial budget analysis

Economic analysis was done using the partial budget analysis as described by CIMMYT (1988) to determine the economic feasibility of the fertiliser application. It was calculated by taking into account the additional input cost involved and the gross returns obtained from different treatments. The variable cost also included the labour cost involved for harvesting, threshing and winnowing of the produce as it varied according to the yield obtained from a particular treatment.

The net returns were calculated by subtracting the total cost of treatment from its gross returns: NR = GR - VC

where NR = net returns, GR = gross returns, VC = variable cost.

Results and discussion

Effects of bio-fertiliser and inter-row spacing on days to 50% flowering, leaf area index and number of effective nodules

Days to 50% flowering

Result showed that, days to 50% flowering was affected by bio-fertiliser levels, row spacing and their interaction which was highly significant ($P \leq 0.001$). Table 1 shows that the longest days to 50% flowering (69) was recorded at the combination of the highest bio-fertiliser rate (0.75kg/ha) and widest inter-row spacing (50 cm), whereas the shortest days (37) was recorded for the control of no bio-fertiliser application and the narrowest inter-row spacing (30 cm). Wider inter-row spacing, which supports nutrient intake and proper photosynthetic light interception, resulted in prolonged days to flowering. Therefore plants with wider inter-planting spacings needed longer days for plant development, when compared to plants with narrower inter-planting spacings. These findings are consistent with those of Birhanu et al. (2018), who revealed that faba beans took more time to bloom when sown at a wider inter-row spacing.

Leaf area index

Leaf area index (LAI) was affected by the main effects of both bio-fertiliser rate and inter-row spacing and their interaction which was highly significant ($P \leq 0.001$). Table 1 shows that the highest LAI (978 cm^2) was recorded from the combination of the highest rate of bio-fertiliser (0.75 kg/ha) and the widest inter-row spacing (50 cm). This is due to minimum competition between plants for nutrients and solar radiation. The lowest LAI (2245 cm^2) was recorded for the control with the narrowest inter-row spacing (30 cm).

Number of effective nodules

The number of effective nodules was affected by bio-fertiliser level and inter-row spacing and their interaction which was highly significant ($P \leq 0.001$). The highest number of effective nodules (22.8) was recorded from the combination of treatments that were inoculated with the highest bio-fertiliser rate (0.75 kg/ha) and the widest inter-row spacing (50 cm); the lowest number of effective nodules (12.5) was recorded for the control and narrowest (30 cm) inter-row spacing (Table 1).

This variation in number of effective nodules among the treatments can be ascribed to the soil containing indigenous rhizobium that could be activated which is effective in nodule formation by rhizobium inoculation. The wide spacing enables plants to get more nutrients, light and water with relatively less competition. The increased nodule number with rhizobium inoculation could be associated with the efficiency of introduced rhizobia to compete with indigenous bacteria dwelling in the soil. This result is in agreement with Birhanu et al. 2018 and with Zerihun and Abera (2014), both of whom reported that seed inoculation with rhizobium inoculum produced significantly higher numbers of effective nodules per plant. Saidi et al. (2014) also found that rhizobium inoculation significantly enhanced nodulation.

Table 1: Effects of bio-fertiliser rate (kg/ha) and inter-row spacing (cm) on days to 50% flowering, leaf area index and number of effective nodules

Bio-fertiliser rate	Inter-row spacing	DF (50%)	LAI(cm^2)	NEN
0	30	37^{l}	225^{l}	12.5^{l}
0	40	38^{k}	246^{k}	13.5^{k}
0	50	40^{j}	278^{j}	14.0^{j}
0.25	30	42^{i}	373^{i}	15.0^{j}
0.25	40	44^{h}	564^{f}	17.0^{k}
0.25	50	46^{g}	794^{c}	21.0^{c}
0.5	30	48^{f}	379^{h}	15.8^{h}
0.5	40	50^{e}	592^{e}	19.0^{e}
0.5	50	54^{d}	966^{b}	22.0^{b}
0.75	30	60^{c}	533^{g}	16.0^{g}
0.75	40	62^{b}	689^{d}	20.0^{d}
0.75	50	69^{a}	978^{a}	22.8^{a}
LSD (0.05)		0.7	4.2	0.7
CV (%).		2.0	0.75	10.8

Means with the same letter in the same column are not significantly different ($P \leq 0.05$).
DF = days to 50% flowering; LAI = leaf area index; NEN = number of effective nodules.

Effects of bio-fertiliser and inter-row spacing on number of leaves per plant, plant height and dry weight of nodules

Number of leaves per plant

The number of leaves per plant was significantly affected by the main effects of bio-fertiliser rate and inter-row spacing ($P \leq 0.001$); however the interaction effects of bio-fertiliser rate and inter-row spacing was not significant. The maximum number of leaves (44) per plant was recorded at the highest bio-fertiliser rate (0.75 kg/ha); whereas the lowest number per plant (22) was recorded for the control of no bio-fertiliser application (Table 2).

This result supports Zerihun and Abera (2014) who stated that rhizobium inoculated plants of faba bean produced significantly higher number of leaves per plant than control. Birhanu et al. (2018) also indicated that climbing bean varieties inoculated with rhizobium showed incremental increases in the number of leaves per plant.

Table 2 shows that the widest inter-row spacing (50 cm) produced the highest number of leaves per plant (33), whereas lowest number (21) was at the narrowest inter-row spacing (30 cm). This might be due to less competition for resources (light, nutrients and water) at a wide spacing and this encourages more vegetative growth and the number of leaves produced. This result is in agreement with Tafere et al. (2012) who stated that more leaves were obtained at wider row spacing for faba bean plantings.

Plant height

Plant height was significantly ($P \leq 0.001$) affected by the main effects of both bio-fertiliser rate and inter-row spacing. The interaction effect of bio-fertiliser level and inter-row spacing was not significant. The maximum plant height (135 cm) was recorded at the highest level of bio-fertiliser (0.75 kg/ha) and the lowest plant height (101 cm) was observed for the control of no bio-fertiliser application (Table 2). Higher plant height could be attributed to the increased vegetative growth associated with a higher bio-fertiliser application level, which in turn improved nutrient uptake efficiency by contributing to available soil N. These results are in agreement with the findings of Birhanu et al. 2018 and Endalkachew et al. 2018, both of whom reported that there was an increase in plant height of lentil in response to inoculation with rhizobium strain.

Table 2 shows that the tallest plant height (129 cm) was recorded at the narrowest inter-row spacing (30 cm) and the shortest plant height (109 cm) was recorded at the widest inter-row spacing (50 cm). This might be attributed to relatively low solar radiation interception in a narrow inter-row spacing as compared to wider one.

Gezahegn et al. (2016) reported that the inter-row spacing of 30 cm resulted in significantly taller plants (104 cm) than at the 40 cm inter-row spacing (99 cm) and the 50 cm inter-row spacing (93 cm). Likewise Khalil et al. (2015*)* stated that dense plantings increase the height of faba bean because of competition between plants. This result is also in agreement with the studies by Taj et al. (2002) and Worku and Demisie (2012).

Dry weight of nodules

Dry weight of nodules was significantly ($P \leq 0.05$) affected by the main effects of bio-fertiliser rate and inter-row spacing ($P \leq 0.001$), but not by their interaction. The highest dry mass of nodules (149 g) was recorded for the treatment inoculated with the highest rate (0.75 kg/ha) of rhizobia, whereas the lowest (67g) was recorded for the control of no bio-fertiliser application (Table 2). This result with respect to dry mass of nodules of faba bean might be attributed to supply of bio-fertiliser to the crop through symbiotic N_2 fixation and changing soil nitrogen to ionic form (NO_3-) made available for plant uptake enabling production of the higher nodule dry weight by initiating vegetative growth (Gedamu et al. 2021). This finding supports Togay et al. (2008) who determined that the observed benefits on legume dry weight of nodules through rhizobium inoculation seems to be through the supply of N to the crop by symbiotic N_2-fixation. Sharma et al. (2000) also reported the significant effect of seed inoculation on dry weight of nodules.

Table 2 shows that the highest dry mass of nodules (124 g) was recorded at the widest inter-row spacing (50 cm) and the lowest (105 g) was at narrowest inter-row spacing (30 cm). This result might be due to wide spaces between the plants decreasing inter-plant competition, resulting in increased plant capacity for utilising environmental inputs in building greater amounts of the metabolites used in developing new tissues and thereby increasing yield components (Taj et al. 2002; Worku and Demisie 2012; Gezahegn et al. 2016).

Table 2: Effects of bio-fertiliser rate (kg/ha) and inter-row spacing (cm) on number of leaves per plant, plant height and dry weight of nodules (g)

Bio-fertiliser rate	NLP	PLH	DWN
0	22^{d}	102^{d}	67^{d}
0.25	28^{c}	112^{c}	108^{c}
0.5	34^{b}	127^{b}	132^{b}
0.75	44	135^{a}	149^{a}
LSD (0.05)	5.1	7.0	7.7
Inter-row spacing			
30	21^{c}	129^{a}	105^{c}
40	27^{b}	119^{b}	114^{b}
50	33^{a}	109^{c}	12a
LSD (0.05)	4.4	6.1	6.7
CV (%)	16.2	6.0	6.9

Means with the same letter in the same column of each factor are not significantly different ($P \leq 0.05$). NLP = number of leaves per plant; PLH = plant height; DWN = dry weight of nodules

Effects of bio-fertiliser and inter-row spacing on faba bean yield components

Number of pods per plant

The number of pods per plant was significantly ($P \leq 0.001$) affected by the main effects of both bio-fertiliser rate and inter-row spacing; the interaction was not significant. Table 3 shows that the highest number of pods per plant (32.9) was recorded at the highest bio-fertiliser rate (0.75 kg/ha), whereas the lowest number of pods per plant (21.6) was recorded for the control of no bio-fertiliser. This finding is in agreement with that of Mekki (2016) who concluded that the higher numbers of pods per plant were observed in bio-fertiliser inoculation in faba bean. The research on groundnut by Dereje (2007) showed that plants that were immunised with rhizobium yielded more pods per plant.

Table 3 shows that the highest number of pods per plant (36.5) was recorded at the widest inter-row spacing (50 cm) and the lowest number (25.4) was recorded at the narrowest inter-row spacing (30 cm). This finding is similar to those of Abdel-Ghaffar (1988), Abdel (2008), Kubure et al. (2016) and Gezahegn (2017); who all found that as planting space is narrowed the intensity of inter-plant competition for different inputs increases and this reduces the number of pods per plant of faba bean.

Number of seeds per pod

The number of seeds per pod was not significantly ($P > 0.05$) influenced by the main effects of bio-fertiliser rate and inter-row spacing, nor by the interaction. Table 3 shows the mean values of seeds per pod for the different rates of bio-fertiliser and for the different inter-row spacings.

Weight of 100 seeds

Seed weight was significantly ($P \leq 0.001$) affected by the main effects of both bio-fertiliser rate and inter-row spacing; the interaction was not significant. Table 3 shows that the highest 100 seed weight (99 g) was recorded at the highest bio-fertiliser rate (0.75kg/ha), whereas the lowest 100 seed weight (63 g) was recorded for the control of no bio-fertiliser. Larger seeds were produced by obtaining more nutrients from higher rates of bio-fertiliser that initiated plant nutrient uptake by changing soil N to ionic form (NO_3). This result is in agrees with a report by Ali et al. (2004) who stated that rhizobium immunisation of chickpea brought a significant effect on 100 seed weight.

Table 3 shows that the highest 100 seed weight (90 g) was recorded at the widest inter-row spacing (50 cm) and the lowest value (76 g) was recorded at the narrowest (30 cm) inter-row spacing. Widely spaced plants get more nutrients, light and water for growth and development leading to more photosynthetic efficiency and creating the probability of accumulating more dry matter that can be partitioned to the seed during the grain filling period. This result is in agreement with Abdel-Ghaffar (1988), Abdel (2008), Kubure et al. (2016) who all reported a decrease in the weight of seeds with higher plant densities.

Above ground dry biomass yield

Above ground dry bio-mass yield was significantly ($P \leq 0.001$) affected by the main effects of both bio-fertiliser rate and inter-row spacing; the interaction was not significant. Table 3 shows that the highest above ground dry bio-mass yield (7994 kg/ha) was recorded at the highest bio-fertiliser rate (0.75 kg/ha), whereas the lowest (3379 kg/ha) was recorded for the control of no bio-fertiliser. Higher rate of rhizobium inoculant caused more vegetative growth.

Table 3 shows that the highest above ground biomass yield (6041kg/ha) was recorded at the widest inter-row spacing (50 cm) and the lowest value (5035 kg/ha) was recorded at the narrowest inter-row spacing (30 cm). Wide spacing gave more light penetration for photosynthesis and thus higher vegetative growth. This result agrees with those of Gezahegn (2017) and Woldekiros et al. (2018), who both found that maximum above ground dry bio-mass of faba bean was obtained when grown at wider inter-row spacing.

Harvest index

Harvest index was significantly ($P \leq 0.001$) affected by the main effects of both bio-fertiliser rate and inter-row spacing; the interaction was not significant. Table 3 shows that the highest harvest index (33%) was recorded at the highest bio-fertiliser rate (0.75 kg/ha), whereas the lowest (24%) was recorded for the control of no bio-fertiliser. Higher rates of bio-fertiliser, initiate higher vegetative growth of the faba bean plant, increasing the total dry bio-mass and grain yield of the plant.

Table 3 shows that the highest harvest index (32%) was recorded at the widest (50 cm) inter-row spacing and the lowest value (26%) was recorded at the narrowest (30 cm) inter-row spacing. Wide spaces between the plants decrease inter-plant competition, leading to increased plant capacity for utilising the environmental inputs in building the metabolites to be used in developing new tissues and increasing yield components which are directly proportional to harvest index. Similar results were reported by Abdel (2008); Gezahegn et al. (2016); Gezahegn (2017) and Birhanu et al. (2018).

Table 3: Effects of bio-fertiliser rate (kg/ha) and inter-row spacing (cm) on number of pods per plant, seeds per pod, 100 seed weight (g), above ground biomass (kg/ha) and harvest index

	NPP	NSP	HSW	AGB	HI
Bio-fertiliser rate					
0	21.6^{d}	3.2	63^{d}	3379^{d}	24^{d}
0.25	25.1^{c}	3.1	77^{c}	4506^{c}	27^{c}
0.5	29.5^{b}	3.1	89^{b}	6193^{b}	30^{b}
0.75	32.9^{a}	3.4	99^{a}	7994^{a}	33^{a}
LSD (0.05)	3.2	0.4	1.9	774	2.2
Inter-row spacing					
30	25.4^{c}	3.3	76^{c}	5035^{c}	26^{c}
40	30.6^{b}	3.2	83^{b}	5478^{b}	29^{b}
50	36.5^{a}	3.2	90^{a}	6041^{a}	32^{a}
LSD (0.05)	5.0	0.4	6.8	434	2.3
CV	14.2	1.2	2.3	4.0	2.8

Means with the same letter in the same column of each factor are not significantly different (P ≤ 0.05). NPP = number of pods per plant; NSP = number of seeds per pod; HSW = 100 seed weight; ADB = above ground biomass; HI = harvest index

Effects of bio-fertiliser and inter-row spacing on grain yield of faba bean

Grain yield of faba bean was significantly (P ≤ 0.001) affected by the main effects of both bio-fertiliser rate and inter-row spacing; the interaction was not significant. The maximum grain yield (2540 kg/ha) was recorded from the treatment combination of the highest rate of bio-fertiliser (0.75 kg/ha) and widest inter-row spacing (50 cm) (Table 4). The lowest grain yield (1083 kg/ha) was obtained from the treatment combination of control (no bio-fertiliser) and the narrowest inter-row spacing (30 cm). This can be attributed to low rate of bio-fertiliser inoculation, and minimum plant stands, resulting in low grain yield.

Maximum grain yield was recorded at widest inter-row spacing due to decrease in the competition for nutrients and solar radiation, which enhance the performance of each plant resulting in increased crop yield. At the narrowest spacing, the effects on the yield were reduced and that can be attributed to inter-plant competition for soil nutrients, light for photosynthesis and floral abortion; all of which cause yield reduction.

This result corresponded to that of Saidi et al. (2014), who concluded that treatments with rhizobium inoculation gave higher grain yield, when compared with those without inoculation. A similar increasing effect of rhizobium inoculation on the production soybean was reported by Abbas et al. (2014). Also Zerihun and Abera (2014) stated that rhizobium inoculation produced significantly higher total grain yield than the control. Singh and Singh (2002); Kubure et al. 2016 and Birhanu et al, (2018) all indicated that the yield potential of an individual plant is fully exploited when sown at wider inter-row spacing.

Table 4: Effects of bio-fertiliser rate (kg/ha) and inter-row spacing (cm) on grain yield (kg/ha) of faba bean

Bio-fertiliser rate	0	0.25	0.5	0.75
Inter-row spacing				
30	1083[hij]	1450[fg]	1587[e]	2317[b]
40	1150[h i]	1483[f]	1917[d]	2383[ab]
50	1216[h]	1550[ef]	2150[c]	2540[a]
LSD(0.05)				148
CV (%)				11.3

Means with the same letter are not significantly different ($P \leq 0.05$)

Partial budget analysis

Raising the productivity of faba bean, will require maximising the net earnings from the yield. A partial budget analysis (Table 5) was calculated by considering the variable input costs involved and the gross returns obtained from the different treatments. Input costs are the cost for bio-fertiliser as well as the costs for planting material and labour for all the activities starting from land preparation to culminating in harvesting. The prevailing local market price (at harvest time) for faba bean was used to determine gross returns. The net return was calculated via subtracting the price of the treatment from its gross return.

The maximum net return (ETB53,850 or US$1843/ha) was attained from the treatment combination of 0.75 kg/ha bio-fertiliser and inter-row spacing of 50 cm; the second highest net return (ETB50,392 or US$1725/ha) was attained by the 0.75 kg/ha bio-fertiliser rate and 40 cm inter-row spacing and the third highest (ETB48,826 or US$1671/ha) was attained by the 0.75 kg/ha bio-fertiliser rate and 30 cm inter-row planting.

Table 5: Partial budget analysis of faba bean in response to bio-fertiliser rate (kg/ha) and inter-row spacing (cm) ETB29.21 = US$1.00

		GY (kg/ha)	AGY (kg/ha)	Cost of bio-fertiliser (ETB/ha)	Other input costs (ETB/ha)	Total input costs (ETB/ha)	GR (ETB/ha)
Bio-fertiliser rate	Inter-row spacing						
0	30	1083	975	0	3000	3000	24,374
0	40	1150	1035	0	3000	3000	25,875
0	50	1216	1094	0	3000	3000	27,353
0.25	30	1450	1305	350	2750	3100	32,625
0.25	40	1483	1335	350	2750	3100	33,374
0.25	50	1550	1395	350	2750	3100	34,875
0.5	30	1587	1428	700	2500	3200	35.701
0.5	40	1917	1725	700	2500	3200	43,126
0.5	50	2150	1935	700	2500	3200	48,375
0.75	30	2317	2085	1050	2250	3300	52,126
0.75	40	2386	2148	1050	2250	3300	53,692
0.75	50	2540	2286	1050	2250	3300	57,150

GY: grain yield; AGY: adjusted grain yield; V-cost: variable cost; TV-cost: total variable cost; GR: gross return; NR; net return

Correlation analysis

Correlation analysis between phenology, growth parameters and yield and yield related traits is shown in Table 6. Number of seeds per pod was significantly correlated with number of effective modules (0.53), number of pods per plant (0.46), days to 50% flowering (0.55), hundred seed weight (0.46), grain yield (0.42) and harvest index (0.33); but not significantly correlated with above ground biomass. Harvest index was significantly correlated with number of leaves per plant (0.32), number of effective nodules (0.45), number of pods per plant (0.42), number of seeds per pod (0.33), hundred seed weight (0.43); but not significantly correlated with dry weight of nodules.

Number of pods per plant was significantly correlated with days to 50% flowering (0.70) number of effective nodules (0.74), leaf area index (0.80), dry weight of nodules (0.63) and grain yield (0.66). Grain yield was significantly correlated with dry weight of nodules (0.56), days to 50% flowering (0.66), number of effective nodules (0.64), leaf area index (0.70), number of leaves per plant (0.63), number of pods per plant (0.66), harvest index (0.47) and above ground bio-mass yield (0.70). These correlations show that the improvement of one parameter was highly dependent on some of the others.

The application of bio-fertiliser with appropriate spacing would improve nutrients uptake of the plant, increases N fixation capacity and reduce competition between plants for resources. This finding was in line with the study by Negasa and Abera (2019) which showed that the seed yield of faba bean was significantly and positively correlated with leaf area index, 100 seed weight, pods per plant and dry biomass.

Similarly, Lopez - Bellido et al. (2005) indicated that leaf area index was positively associated with low plant population (wider space) and negatively correlated to narrow spacing or overcrowded plant population and high grain yield. Another finding by Tekle et al. (2015), and Kubure et al. (2015) stated that the seed yield, growth and yield components showed a significant positive correlations with seed yield, plant height and leaf area index.

Table 6: Pearson correlation coefficients between the variables collected in the investigation on bio-fertiliser and inter-row spacing on faba bean

	DFF	**NLP**	**NEN**	**PLH**	**LAI**	**NPP**	**NSP**	**DWN**	**AGB**	**HSW**	**GY**	**HI**
DFF	1.00											
NLP	0.79**	1.00										
NEN	0.79**	0.69**	1.00									
PLH	0.52**	0.56**	0.66**	1.00								
LAI	0.92**	0.80**	0.80**	0.60**	1.00							
NPP	0.70**	0.65**	0.74**	0.48**	0.80**	1.00						
NSP	0.55**	0.48**	0.53**	0.58**	0.61**	0.46**	1.00					
DWN	0.67**	0.52**	0.60**	0.32*	0.70**	0.63**	0.45**	1.00				
AGB	0.46**	0.30^{ns}	0.56**	0.48**	0.50**	0.54**	0.22^{ns}	0.61**	1.00			
HSW	0.79**	0.62**	0.62**	0.55**	0.80**	0.56**	0.46**	0.56**	0.48**	1.00		
GY	0.66**	0.63**	0.64**	0.63**	0.70**	0.66**	0.42**	0.56**	0.70**	0.74**	1.00	
HI	0.48**	0.32*	0.45**	0.38*	0.40*	0.42**	0.33*	0.28^{ns}	0.27^{ns}	0.43**	0.47**	1.00

*: significant at P ≤ 0.05 **: significant at P ≤ 0.0; ns: not significant; DFF: days to 50% flowering; NLP: number of leaves per plant; NEN: number of effective nodules; PLH: plant height; LAI: leaf area index; NPP: number of pods per plant; NSP: number of seeds per pod; DWN: dry weight of nodules; AGB: above ground biomass; HSW: hundred seed weight; GY: grain yield; HI: harvest index

Conclusion

The experimental results on faba bean indicated that main and interaction effects of bio-fertilizer and inter-row spacing were highly significant for days to 50% flowering, number of effective nodules, leaf area index and grain yield. The main effects of bio-fertiliser rate and inter-row spacing were significant for plant height, number of leaves per plant, number of pods per plant, dry weight of nodules, above-ground dry biomass yield and harvest index. Grain yield was significantly and positively correlated with yield and yield attributes.

The improvement in the yield attributes and seed yield per hectare with applications of rhizobium bio-fertiliser at the rate of 0.75 kg/ha and 50 cm inter-row plant spacing gave the highest faba bean yield of 2540 kg/ha at the study location. However, this finding requires confirmation by further studies to reach valid and concrete recommendations across different agro ecologies in Ethiopia.

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