The Journal of Agricultural Sciences - Sri Lanka
Vol. 18, No 2, May 2023. Pp 193-208
http://doi.org/10.4038/jas.v18i2.10253

Response of Faba Bean (*Vicia faba* L.) Grain Yield to Biofertilizer Rates and Inter Row Spacings at Kaffa Zone, South Western Ethiopia

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Received:07th July 2021 / Accepted: 02nd February 2023

ABSTRACT

Purpose: *Soil nutrient depletion and crop management practices are the significant factors affecting faba beans production over the world. Biofertilizers can improve soil fertility and health. Moreover, it adds essential nutrients and improves water retention in the soil. Thus, its use is unquestionable to maintain soil fertility and enhance crop production. Hence, biofertilizer rates and inter-spacings were used to enhance faba bean production.*

Research Method: *The Field trials were performed to determine the response of faba bean (Vicia faba L.) grain yield to bio-fertilizer rates and row spacings in the main growing season in 2019 at Kaffa zone, Southwestern Ethiopia. Factorial combinations of four rates of bio-fertilizer (0, 0.25, 0.5, and 0.75kg/ha) and three inter-row spacings (30, 40, and 50cm) were carried out in RCBD with three replications. The LSD test was done at α = 0.05 level of probability.*

Findings: *The results of ANOVA presented that the main effect, as well as the interaction effects of biofertilizers and row spacing, have a significant effect on the yield of faba bean. The pods/plants number, hundred seed weight, and HI are mainly affected by biofertilizer rates and row spacings. The combination of 0.75kg/ha of biofertilizer rates and 50cm of space between rows recorded the maximum pods per plant in number, the weight of hundred seeds, grain yield, and harvest index. The highest grain yield (2540±276kg/ha) was attained with the application of 0.75kg/ha of bio-fertilizer and 50cm of distance between rows, whereas, the lowest (1083.3±117.7kg/ha) was observed from the null treatments and the smaller spacing between rows (30cm).*

Generally, the significantly maximum yield was obtained because of the maximum rate of bio-fertilizer with the widest inter-row spacing in this experiment. Therefore, inoculation of bio-fertilizer at a dosage of 0.75kg/ha with a row distance of 50cm was found to be optimum for the maximum yield of faba bean in Southwestern Ethiopia and other similar agroecologies. It is further recommended that this result is from only one season at one site and hence this study may be repeated in space and time to reach a concrete recommendation.

Research Limitation: *Additional authentication and trials across similar agroecology would be essential to make conclusive recommendations since the field trials were directed for sole cropping season and a site.*

Originality/ Value: *This is an organic fertilizer that could be used by farmers and investors in the future, to increase the production of faba bean.*

Keywords: *Faba bean, Grain yield, Inter row, Legumes, and Rhizobium*

INTRODUCTION

FAO dedicated the word "beans" accustomed to the crops that are harvested only from dry seeds

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(Nataraja & Sons, 1960). Legumes are important because of their high protein and essential amino acid content. In most of the developing countries, the consumption of faba bean is increased compared to the developed countries and this is due to the reduction in consumption of meat. Cereals and legumes are the world's second-largest family of cultivated plants after Gramineae (Christine *et al.,* 2017; Erana, 2020). According to FAO, (2019), Erana and Zelalem, (2020) the world's average annual output of cereals and pulses from 2008 to 2017 was close to 75.68 million tons. Next to coffee and Sesame, faba bean production is the third-largest export crop and it is popular in production and nourishment, as a profitable basis of protein, hence it accounts for fifteen percent of intake and the major source of income from high-quality plants (Mulugeta *et al.,* 2015; Getachew, 2019). In addition, Osman *et al.,* (1988) and Erana, (2020) reported that leguminous crops have numerous merits in improving soil fertility through the biological process of nitrogen fixation, stock feed, erosion control, supply of fuel, and a spread of different advantages (Prakash and Murugan, 2009; Muoni *et al.,* 2019). The main reason that makes the country a high grower and producer of grain legume crops is due to the presence of favorable/ conducive soil conditions and the suitable agroecological situation in Ethiopia. Likewise, Getachew (2019) reported that due to the huge production of grain legumes, Ethiopia is one of the top supplier countries at the international level (USDA Foreign Agricultural Service, 2018).

Considering the production area, faba bean is the fourth major significant legume crop in the world (Kebede, 2020). The crop has many uses and is eaten in the form of dried kernels, fresh vegetables, or processed foods. In addition to the availability of high concentration and quality of proteins, the different parts of faba beans are used for multi-purposes such as fodder for animals in the form of dried straw and seed, and green shrubs as fresh (Yasin and Esrael, 2017; USDA Foreign Agricultural Service, 2018).

Over the World, Ethiopia is the 2nd largest faba bean producer after China; its share accounts for only 6.96% of global production and 40.5% of Africa's (Chopra *et al.,* 1989; James, 2000; Tekley *et al.,* 2014; Yohannis *et al*., 2015; Ashenafi and Mekuria, 2015). Concerning area and production in Ethiopia, it is foremost the pulse group. The total area coverage of its production in Ethiopia on private peasant fields was 437,106.04ha which contributes 3.01% of total field crop production. Between the contributions of the various ethnic groups in the South and the regional nation-states, 14.08% of the bean cultivation area accounts for 12.29% of the nationwide bean output (CSA, 2018). "Of the entire regional area under pulse crop production (219,502.58 hectares), 3.34% is covered by faba bean and accounts for 3.32% of the total pulse production of the country (CSA, 2018). The total area coverage of faba bean in the Kaffa Zone in the 2018 main cropping season was 14533ha (KZAD). In Ethiopia, the crop grows mainly because the chilling requirement is fulfilled by cold temperatures in the high elevation of the mountains from altitudes of 1900 - 3000 m.a.s.l and sometimes even higher (Kebede, 2020).

Faba beans have several advantages in the economic life of the agricultural communities of the country's highlands (Fekede *et al.,* 2018). Similarly, they reported that besides its important role in soil fertility maintenance, it is used as food, feed for livestock, and means of income for farmers. Moreover, faba beans are very rich in protein contents and it is rich in antioxidants, vitamins, and minerals useful for healing. In Ethiopia, all aspects of life are closely related to faba bean (Teklay *et al.,* 2014; Yohannis *et al*., 2015).

Driven by rapid population growth, demand continues to grow, and the imbalance between supply or producers and demand endures to widen. However, the average legume production of smallholders does not exceed 2100kg/ha in Ethiopia (CSA, 2018). Despite its multiple benefits, the productivity of faba beans is 1893 and 1639kg/ha at the national and regional levels respectively, which is still low compared to its achievable, yield >2100kg/ha (CSA, 2018). Numerous issues affect the production and productivity of faba beans, like soil infertility, inappropriate plant density and sowing time, poor farm practices, pests, and disease. Based on numerous researches conducted in Ethiopia, there are important variances in the grain yield and performance traits of faba beans in terms of plant spacing and soil fertility (Bezabih *et al.,* 2018).

External stresses are the most detrimental factors influencing the production of crops; as a result, the productivity of faba bean is deteriorating at an unparalleled degree. The excessive reliance of most farmers and investors on chemical fertilizers and other chemical pesticides to quell encroachment and feed an increasing population has fortified industries to produce potentially lethal chemicals like pesticides or fertilizers (Trishna *et al.,* 2016). Likewise, they reported that these chemicals are not only harmful to humans but also seriously affect the ecological balance of the environment. Under such unfavorable circumstances, biological fertilizers can be used as a powerful substitute, not only to feed the emerging population, but also to protect agriculture from various severe environmental pressures. Consequently, it is necessary to recognize the significant and useful features of bio-fertilizers and implement their applications in present agriculture.

Bio-fertilizer (Biological Nitrogen Fixation) is a promising marginal solution and technology plays a vital role in plummeting fertilizer nitrogen consumption, improving soil fertility, reducing production costs, and eliminating the adverse effects of fertilizer pollution on the environment (Sameh *et al.,* 2017; EIAR, 2018; Kebede, 2020). Nitrogen-fixing nutrients can be used in the soil. Meanwhile, biological fertilizer is theoretically alive; it can co-exist with plant roots (Burra, 2020). Heba *et al.* (2021) reported that the microorganisms involved can easily and securely alter complex organic substances into simple compounds, which can be easily absorbed by plants. The action of the microorganisms lasts a long time, which improves the fertility of the soil (Getachew, 2019). Also, the cost/ha of bio-fertilizer is cheaper than chemical fertilizer.

The planting population of crops is important for large-grained seed varieties and it has been recognized as the main determinant of crop yield (Janusz, 2022). Optimal plant density (that is, the smallest population that produces the highest yield) and the appropriate design of plants per area allow crops to use resources in the best way and produce maximum grain yields (Kebede, 2020).

According to the Kaffa zone Agriculture Department 2018 *(unpublished)* poor soil fertility, soil acidity, inappropriate plant density, and weed infestation were the major problems for faba bean production in the study area. This is due to topsoil in the South Western Ethiopia high lands having been eroded for centuries by torrential rains, aided by poor soil management and lack of proper erosion control practices. The consequence of high rainfall resulted from soil acidity by leaching of micronutrients that are very essential for plant growth. Furthermore, plant density is a critical problem in Kaffa zone, because except for broad-casting another way of planting system is still unknown by the farmer of the study area. Also, the adoption rate of improved production technologies has been very poor among farmers. Demonstrations and popularizations have been done in very few areas since the productivity of faba beans on model farmers' fields was still low (1500kg/ha) in Kaffa Zone (KZAD). In the 2018 cropping season, the average yield of faba beans in the Kaffa zone was 1450kg/ha. Especially two factors, inter-row spacing, and soil fertility problems were the most limiting factors for yield and its related characteristics of faba bean productivity in the Kaffa zone. But these constraints were not yet further studied and researchers still have not assessed them widely in the study area. Thus, the study was initiated to evaluate the effects of bio-fertilizer rate and inter-row spacings on yield and yield components of the faba bean at Kaffa zone, Southwestern Ethiopia.

MATERIALS AND METHODS

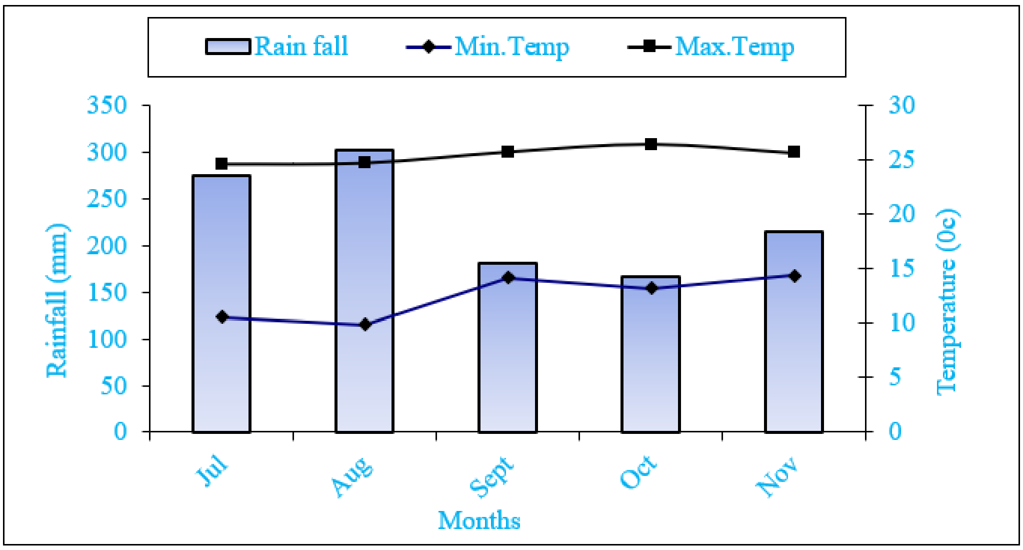
Experimental Area

The field trial was performed in the 2019 main cropping season at Bonga Agricultural Research Center, Alargata sub experimental station, Kaffa zone, Southwestern Ethiopia (07^0, 17' north to 08^0, 08' north latitude, and 35^0, 30' east to 36^0, 43' east longitude). The study area is 476km far from Addis Ababa and 12km from Bonga town (headquarters of Kaffa zone). The altitude of the study area was 2500 m.a.s.l. The rainfall pattern has a bimodal distribution, with "Belge" (February-May) being the light rainy season, and "Meher" (June-October) being the main rainy season. The climatic conditions of the monthly max T°, min T°, and monthly RF in the 2019 growing season (July-November) in the experimental area are shown in Figure 01.

Materials

The Rhizobium strain (HUFBR-15) bio-fertilizer was used because of its wide adaptation to high land soil conditions and high rainfall areas (Bayou *et al.,* 2021). The inoculums were produced by mixing culture liquid medium containing 108 viable rhizobia mL-1 with well-decomposed filter mud (Bezabih *et al.,* 2018). This production was undertaken at the bio-fertilizer research and production laboratory of Melkassa agricultural research center, Ethiopia on August 1/2019. The viability test of faba bean seeds was taken with the water suspension method before planting. The viability of used seed samples was 97%.

The variety of faba bean "Tumsa" was used as a test crop because of its high-yielding ability and appreciable agronomic performance throughout the country (MoARD, 2015). The Holleta research center released this variety which was very high in its yield production and favorable agronomic characteristics. Depending on the variety and weather conditions, the variety matures in 90-120 days. The average yield obtained by different researches which are nationally accepted from this variety was 1520kg/ha (CSA, 2017). The overall characteristics of the variety were shown in Table 1. The seed source was Bonga agricultural research center. The institution made this variety adaptation trial continuously in Southwest Ethiopian highlands and started distribution for farmers of the Kaffa zone. Also, the germination percentage was tested at the experimental site, and 97% germinated successfully.



Source: Wush-Wush Tea development Weather and Meteorology Station (2019)

Figure 01: Chart of temperature and precipitation in the Kaffa zone, Southwestern Ethiopia, the experimental area, during 2019

Table 01: Description of faba bean variety 'Tumsa' used in the experiment

Characteristics	Values
Altitude	1100-2800 m.a.s.l
Temperature	20-25°C
Rainfall	1200ml
Growth habit	Bush
Flower color	White
Days to maturity	90-120
Average yield at research (kg/ha)	1520
The yield on farmers fields (kg/ha)	1050

Kg/ha: Kilogram per hectare; Source: MoARD (2015)

Treatments and Experimental Design

Treatments: Treatment entails four rates of bio-fertilizer (0, 0.25, 0.5, and 0.75kg/ha) and three different inter-rows spacings (30, 40, and 50cm) between rows. The combinations having twelve total treatments were replicated three times and the total experimental units were 36. The treatment combination is illustrated in Table 02.

The field experimental design: The field trial was performed with a group of RCBD factors and each was replicated three times and twelve treatments. The 50cm row spaced plot consisted of five rows, and samples were taken from the three central rows of five randomly selected plants. The 40cm row spacing plot consisted of six rows, and samples were taken from the three central rows of five randomly selected plants. The plot of 30cm inter-row spacing consisted of seven rows and similarly, samples were taken from central three rows from five randomly selected plants. The plot had a 2m width and a 1m length. The space between blocks was maintained at 1m apart and within plots was 0.5m. Then the gross plot size was 2m × 1m= $2m^2$. The first row on each side of the plot was taken as an edge effect. The second row on each side of the plot was selected as the sampling row. Therefore, the net productive size of the plot was 1.8m x 1m =$1.8m^2$.

Table 02: Explanation of treatments

Treatments	Bio-fertilizer rate (kg/ha)	Inter-row spacing (cm)
T1	0	30
T2	0	40
T3	0	50
T4	0.25	30
T5	0.25	40
T6	0.25	50
T7	0.5	30
T8	0.5	40
T9	0.5	50
T10	0.75	30
T11	0.75	40
T12	0.75	50

Experimental Procedure and Crop Management

To obtain a seedbed with well-developed roots, the experimental field was plowed 3 times with a tractor and the plot was physically leveled. A germination test was done at the experimental site before planting and 95% of the seeds were germinated. Considering the biofertilizer rate, the blanket national recommended rate is 0.5kg/ha (MoARD, 2015). The crop seeds were splashed with clean H_20 then exposed to the sun to become dried, and immersed in the cell suspension Rhizobium strain for 30 minutes before planting by the above-mentioned rates. 10% sugar solution was added as an adhesive agent before inoculation to stick inoculants with faba bean seeds and the water was slightly boiled to support sticking inoculants with seeds more.

The nationally recommended planting distance for broad beans in Ethiopia is 40cm and the planting distance is 10cm (MoA, 2015). Therefore, to compare the effect of spacing, three selected inter row spacing (30cm, 40cm, and 50cm) were used. The seeds were planted manually by the above-mentioned spacing and seeds were planted by nationally recommended seeding depth which was 5cm. Weeding continued after 3 weeks and totally the crop was weeded 3 times in this sequence. Harvesting was done after full maturation by hand after 120 days of planting.

Soil Analysis Result

Used an auger composed according to the procedure of Okalebo *et al.* (2002) to collect a depth (20cm) from the sampling point through the experimental field in a zigzag pattern in a band pattern, mixed it with the plastic sheet, and then air-dried the soil sample at room temperature, packed and transported to the Plant and Soil Tissue Analysis Laboratory of Jimma Agricultural Research Institute. Used laboratory standard procedures to analyze composite soil samples to determine soil texture, soil pH, OC, total N, available P, and CEC.

N (total nitrogen) of the soil was analyzed based on the Kjeldahl technique (Keeney and Nelson, 1982; Borsali and Zadi, 2014) and available phosphorus (P) was estimated based on the Bray II technique. Organic carbon (OC) of the soil was analyzed by the Walkley and Black method, (1934). Soil pH was estimated in the soil-water suspension technique with the help of a pH meter. Soil CEC was determined based on the ethanol 95% extraction technique (FAO, 1990).

The soil analysis result before sowing obtained from the Jimma agricultural research institute soil and plant tissue analyzing laboratory showed that the soil consisted of 50% sand, 44% clay, and 6% silt, resulting in the soil textural class was sandy clay. With this, pH=6.00 which is slightly acidic, available “P” = 65.76 high ppm, OC = 2.64% which is low, total “N” = 0.39% which is very high, and CEC (Meq/100g) = 20.64 which is medium (FAO, 1990). The general soil physiochemical properties analysis was illustrated in Table 03.

Table 03: Laboratory result of designated physio-chemical characteristics of the soil of the study area

Soil properties				
Physical analysis		Chemical analysis		
Characters	Values	Characters	Values	Reference
Sand%	50	N	0.39	Kenny and Nelson, 1982
Silt%	44	P	65.76	Bray II technique
Clay%	6	OC	20.64	Walkley-Black method, (1934).
Textural class	Sandy clay	CEC	2.6	Ethanol 95% extraction technique

Where; - N=total nitrogen in the soil, OC=organic carbon in the soil, Av. P=available phosphorous in soil and CEC=cat-ion exchange capacity

Data Collected

Several yield data components to actual yield and important parameters were considered in this study. Yield parameters such as the number of seeds per pod, the pods/plant in number, AGBY (biomass yield) in kg/ha, the weight of 100 seeds (g), Grain yield in kg/ha, and Harvest index (%) were determined after maturation and at harvest time, and then by using random method, sfive protected plants were occupied from the middle tree ridge rows of each plot to be estimated. Furthermore, the sampled seeds were taken to oven-dried at 70 degrees Celsius for 48 hours at Bonga seed quality control and testing center. Finally, grain yield was recorded from the gross plot area of all plots after sun-dried at room temperature and trashed.

Data Analysis

The collected data were summarized and exposed to the ANOVA procedure of factorial combination of RCBD by 9.3 version SAS software (SAS, 2009). The LSD test was done at α = 0.05 level of probability.

RESULTS AND DISCUSSION

Grain Yield and Its Components

Number of pods/plant: The outcome of ANOVA revealed that the main effects of Rhizobium inoculation significantly influenced the number of pods/plants (Table 4). The application of bio-fertilizer and inter-row spacing was also significantly ($P<0.001$) influenced.

The maximum number of pods/plant (32.9±3.57) in number was recorded at the application of the highest bio-fertilizer dosage (0.75kg/ha) inoculation while; the lowermost (21.6±2.35) pods/plant in number was noted from the control treatments (Table 04). This might be by the initiation of Rhizobium Inocula for more vegetative performance and grain yield increment of crops when added by the highest rate. This finding is consistent with the work of (Tolera and Zerihun, 2018), who concluded that the inoculation of broad beans with biological fertilizers will increase the pods/plant in number.

Table 04: The main effects of bio-fertilizer (kg/ha) rates and inter-row spacings (cm) on the pods / plant (no) in the main growing season of 2019 in the Bonga Agricultural Research Center of Kaffa zone

	Pods/plant (No)
Bio-fertilizer rate (kg/ha)	
0	21.6±2.35[d]
0.25	25.1±2.73[c]
0.5	29.5±3.20[b]
0.75	32.9±3.57[a]
LSD	3.2
Row spacings	
30	25.4±2.76[c]
40	30.6±3.32[b]
50	36.5±3.96[a]
LSD	4.96
CV	14.2

Means with similar letters within the columns of each factor do not significantly effect; CV: Coefficient of variance: LSD: Least Significance Differences

Likewise, the row spacing showed a significant difference in the number of pods per plant. Therefore, the highest number of pods per plant (36.5±3.96) was recorded in the row spacing (50cm), while the number of seeds recorded was the smallest (25.4±2.76) and the row spacing was the narrowest (30cm) (Table 04). This might be due to the wide space between plants due to reduced competition between plants, which leads to an increase in the ability of plants to use environmental inputs to build a large number of metabolites for the development of new tissues and increase their yield and its components. This outcome is consistent with Kubure *et al.,* (2016) who expressed that the lessening in the number of stems/plant in faba beans is due to a decrease in the number of stems/plant at the highest crop density.

Number of seeds/plant: Analysis of variance indicated that both the main and the interaction effects of bio-fertilizer application dosage and inter-row spacing of faba beans did not show a significant difference in seeds/pods in number (Table 05).

This is because the number of seeds per pod is mainly controlled by genetics and is hardly affected by environmental factors. Gebre-Egziabher *et al.,* (2014) support this result. Likewise, Abebe and Tolera (2017) explained that because of the various rates of fertilizer, the application of Rhizobium inoculation dosage, and the application rate of lime, the number of seeds/plants of faba bean did not have significant impacts.

100-Seed Weight:

The result obtained from this research showed that a hundred seed weight was significantly ($p<0.001$) influenced due to both bio-fertilizer application dosage and inter-row spacing of faba bean (Table 06), whereas, the interaction effect was not significant ($P>0.05$) influenced.

The highest 100 seeds weight (98.8±10.7g) was observed from the application of the maximum (0.75kg/ha) rate of bio-fertilizer inoculation whereas; the lowest value of 100-grain weight (62.9±6.83g) was obtained from the control (Table 06). This is because larger seeds were yielded by obtaining more nutrients from the highest rate of bio-fertilizer inoculation that initiates the plant's nutrient uptake by changing soil N to ionic form (NO_3^-).

Table 05: The interaction of the amount of bio-fertilizer rate (kg/ha) and inter-row spacing (cm) on seeds/pod in number at Bonga Agricultural Research Center, Kaffa zone, 2019.

Number of seed per pods	
Bio-fertilizer rate (kg/ha)	
0	3.2±0.35
0.25	3.1±0.33
0.5	3.1±0.33
0.75	3.4±0.36
LSD	0.4 ns
Row spacings	
30	3.25±0.35
40	3.25±0.35
50	3.16±0.34
LSD	0.4 ns
CV	14.2

NS: mean values are not significantly influenced; Means with similar letters within the columns of each factor do not significantly affected at (P<0.05) probability level; NSP- is seeds/pod in number

This study is reliable with the results of Bezabih *et al.* (2018), who pointed out that faba bean inoculation had a significant impact on the weight of one hundred chickpea seeds.

Similarly, the row spacing shows a significant difference in 100-grain weight. Therefore, the maximum weight value of 100 seeds (90.2±9.80g) is recorded at the maximum row spacing (50cm); where as the lowest value of 100 seeds weight (76±8.26g) is recorded at the narrowest line spacing (30cm). This is because widely spaced plants get more nutrients, light, and water for growth and development with less competition and advanced for more photosynthetic efficiency and this creates the probability of accumulating more dry matter that can be partitioned to the seed during the grain-filling period. This finding is consistent with Abdel-Rahman *et al.,* (2014); Kubure *et al.,* (2016) where it is reported that the weight of seeds with upper plant density will decrease.

Above-ground dry biomass yield: The result obtained from this experiment showed that the above-ground dry biomass yield was significantly affected by both bio-fertilizer dosage and inter-row spacing of faba bean (Table 07). The supply of bio-fertilizer rate and inter-row spacing of faba beans was significantly (P<0.001) influenced. On the other hand, there was no significant parity between the application of bio-fertilizer rate and inter-row spacing of faba bean.

The maximum above-ground dry biomass yield (7994.4±868.9kg/ha) and the highest application rate of bio-fertilizer (0.75kg/ha) were at the same time; the lowest above-ground dry biomass yield (3379.1±367.3kg/ha) was recorded in the control (Table 07). This may be due to the beginning of the inoculation of rhizobia to promote vegetative performance and increase the grain yield of crops when added in high doses.

Correspondingly, the highest (6041±656.6kg/ha) AGDBY was obtained at the broadest (50cm) row spacing whereas; the minimum AGDBY (5035±547.2kg/ha) was observed from the narrowest inter-row spacing (30cm) (Table 07). This could be the initiation of wide spacing for more vegetative performance with low competition; more light penetration for photosynthesis made plants accumulate more assimilates and yield increment of faba bean by wide spacing.

Table 06: Interaction of bio-fertilizer application dosage (kg/ha) and row spacing (cm) on 100 Seed Weight (g) from Bonga Agricultural Research Center in Kaffa zone in 2019

	100 seed weight (g)
Bio-fertilizer rate (kg/ha)	
0	62.9±6.83[d]
0.25	77.1±8.38[c]
0.5	89.3±9.70[b]
0.75	98.8±10.7[a]
LSD	1.92
Row spacings	
30	76±8.26[c]
40	82.9±9.01[b]
50	90.2±9.80[a]
LSD	6.8
CV	2.32

NS: mean values are not significantly influenced; Means with similar letters within the columns of each factor do not significantly affected at (P<0.05) probability level; NSP- is seeds/pod in number

Table 07: The Response of faba bean above-ground dry biomass yield (kg/ha) to the application of bio-fertilizer rate (kg/ha) and row spacing (cm) at Kaffa Zone in the 2019 main growing season.

	above-ground dry biomass yield
Bio-fertilizer rate (kg/ha)	
0	3379.1±367.3[d]
0.25	4505.6±489.6[c]
0.5	6193.3±673.1[b]
0.75	7994.4±868.9[a]
LSD	574.2
Row spacings (cm)	
30	5035±547.2[c]
40	5478.3±595.4[b]
50	6041±656.6[a]
LSD	434.3
CV	4.04

Means with similar letters within the columns of each factor do not significantly (P<0.05) affected at probability level

In addition, this result may be due to the wider space between plants resulting in less competition between plants, which results in plants having a greater ability to use environmental inputs to build a large number of metabolites, which will be used to develop new fabrics and increase its performance components. This result is consistent with Almaz *et al.,* (2016), who found that the airborne dry biomass of broad beans is the largest, and the row spacing is wider.

Grain yield: The ANOVA data showed that the minimum and interactive effects of biological fertilization and row spacing had very significant changes in faba bean grain yield (P<0.001) (Table 8).

The maximum yield (2540±276kg/ha) was observed by the interaction between the highest use of bio-fertilizers (0.75kg/ha) and the largest row spacing (50cm), followed by (2383.3±259kg/ha) the use of bio-fertilizers (0.75kg/ha) and row spacing (40cm) and (2316.7±251.8kg/ha), which are obtained from the ratio of biological fertilizer (0.75kg/ha) and row spacing (30cm) (Table 08). There were no significant differences between the previous treatments, but significant differences were shown in the remaining treatments (Table 8). In contrast, the lowest grain yield (1083.3±117.7kg/ha) comes from the control and the narrowest row spacing (30cm).

It might be attributed to the highest rate of bio-fertilizer inoculation, the enhanced presence of excess soil nitrogen promotes the uptake and nutrient efficiency by plants through roots due to N_2 fixation and changing soil N to ionic form (NO_3^-). At the widest inter-row spacing, the result might be due to reducing competition between plants, so that plants are more capable of using environmental inputs to build a large number of metabolites, which will be used for the development of new tissues, thereby improving their performance components, and advanced for more photosynthetic efficiency and this creates the probability of accumulating more dry matter that can be partitioned to the seed during grain filling period. At the narrowest spacing, note the adverse effects on yield, which may be due to fierce competition between plants and abortion of flowers, and the reduction in yield per plant at control was the unavailability of soil nutrients for plant uptake compared to inoculated.

Table 08: The interaction effects of biofertilizer rates (kg/ha) and inter-row spacing (cm) on grain yield of faba bean in the main season of 2019 at Bonga Agricultural Research Center in Kaffa Zone.

	Bio-fertilizer rate (kg/ha)			
	0	0.25	0.5	0.75
Row spacings (cm)				
30	1083.3±117.7[hij]	1450±157.6[fg]	1586.7±172.5[e]	2316.7±251.8[b]
40	1150±125[hi]	1483.3±161.2[f]	1916.7±239.6[d]	2383.3±259[ab]
50	1215.7±132.1[h]	1550±168.5[ef]	2150±233.7[c]	2540±276[a]
LSD (0.05)	148.36			
CV (%)	11.3			

Means with similar letters within the columns of each factor do not significantly (P<0.05) affect at probability level; GY= grain yield.

Also, yield reduction at narrow inter-row spacing (30cm) could be explained by the early stages of this treatment, the canopy is not developed enough to exploit light interception and photosynthesis. This result is consistent with the outcomes of Sajid *et al.,* (2014), who determined that treatments with rhizobia inoculation produce maximum yields than treatments without Rhizobium inoculation. Abdel-Rahman *et al.,* (2014) also reported increase in soybean yield by rhizobia inoculation. In addition, Abebe and Tolera (2014) indicated that the total grain yield produced by the inoculation of rhizobia was significantly higher than the control treatments. Furthermore, this result is a collaboration with Tamirat (2019), also showed that when plants/crops are planted with a distance or wider inter-row spacing, the yield potential of each plant/crop is used.

Harvest Index:

Analysis of variance indicated that the harvest index was significantly affected by the main effects of the application dosages of bio-fertilizer and inter-row spacing (Table 09). The main effects of the application of bio-fertilizers and the spacing between rows were very significant (P<0.001).

In this experiment, the highest HI (32.8±3.56%) was obtained with the maximum bio-fertilizer dosage (0.75kg/ha); the minimum HI (24.7±2.68%) was recorded in the control. Because increasing the bio-fertilizer rate initiates the vegetative growth of faba bean plant (Table 9). This also increases the total dry biomass and grain yield of the plant. This growth was directly proportional to the harvest index. In addition, row spacing has a significant impact on HI. Therefore, the highest HI (31.9±3.46%) was recorded at the wider line spacing (50cm); the lowest HI (26±2.82%) was recorded at the narrowest row spacing (30cm) (Table 9). These results may be due to the wider space between plants due to less competition between plants, which results in plants having a greater ability to use environmental input to build a large number of metabolites and these metabolites will be used for the development of new tissues, development and increase its proportional performance components with HI. Tamirat (2019); Tamirat and Tilahun (2020) reported similar results, and they recorded a higher all-out harvest index in the broader row spacing of teff than in the narrower inter-row spacing.

Table 09: The main effects of bio-fertilizer rates (kg/ha) and inter-row spacings (cm) of faba bean on harvest rate (%) at the Bonga Agricultural Research Center in Kaffa zone in 2019.

	Harvest Index (%)
Bio-fertilizer rate (kg/ha)	
0	24.7±2.68[d]
0.25	27.3±2.96[c]
0.5	30±3.26[b]
0.75	32.8±3.56[a]
LSD	2.2
Row spacings (cm)	
30	26±2.82[c]
40	29.5±3.20[b]
50	31.9±3.46[a]
LSD	2.3
CV	2.79

Means with similar letters within the columns of each factor do not significantly (P<0.05) affected at probability level; where HI is harvest index

CONCLUSION

1st, due to the combination of a biological fertilizer application rate of 0.75kg/ha and an inter-row spacing of 50cm, the maximum grain yield per hectare (2540±276kg/ha) was recorded. Furthermore, due to the combination of a bio-fertilizer application of 0.75kg/ha and row spacing of 40cm (2383.3±259kg/ha), the grain yield per hectare and the combination of biological fertilizer application of 0.75kg/ha and row spacing of 30cm (2316.7±251.8kg/ha). The yield per hectare is significantly different from the highest yield in this experiment.

2nd, the maximum grain yield per hectare was obtained with integrated applications of rhizobium inoculation at the dosage of (0.75kg/ha) and widest inter-row spacing (50cm). Therefore, this combination was found to be the best combination of the treatments to boost the yield of faba bean in the study district and other the same agroecologies. Though this preliminary generalization is based on a place and a season, more research and confirmation are needed to arrive at effective and specific recommendations.

REFERENCES

Abdel-Rahman, M.S.S., Abbas, H.S. and Haridy, A.G. (2014). Testing of Some New Genotypes of Faba Bean Grown at Different Plant Densities. *Asian Journal of Crop Science,* 6, 67-74. DOI: 10.3923/ajcs.2014.67.74

Abebe, Z. and Tolera, A. (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. Corpus ID138437208

Almaz, M.G., Kindie, T., Sharma, J.J. and Belel, M.D. (2016). Determination of optimum plant density for faba bean (*Vicia faba* L.) on vertisols at Haramaya, Eastern Ethiopia, *Cogent Food & Agriculture,* 2 (1), 1-10. DOI: 10.1080/23311932.2016.1224485

Ashenafi, M. and Mekuria, W. (2015). Effect of Faba Bean (*Vicia faba* L.) Varieties on Yield Attributes at Sinana and Agarfa Districts of Bale Zone, Southeastern Ethiopia. *Jordan Journal of Biological Sciences,* 8 (4), 281 – 286. DOI:10.12816/0027064

Bayou, B.A., EwusiMensah, N., Vincent, L. and Demelash, K.H. (2021). Legumerhizobium specificity effect on nodulation, biomass production and partitioning of faba bean (*Vicia faba* L.). *Scientific Reports,* 11, 3678. https://doi.org/10.1038/s41598-021-83235-8

Bezabih, W., Walelign, W. and Girma, A. (2018). Response of Faba bean (*Vicia faba* L.) to Rhizobium Inoculation, Phosphorus and Potassium Fertilizers Application at Alicho Wuriro Highland, Ethiopia. *Journal of Biology, Agriculture and Healthcare,* 8 (15), 6-9. https://core.ac.uk/download/pdf/234662646.pdf

Borsali, A.H. and Zadi, F.Z. (2014). Ecological Restoration of Forest Soils Case of the Forest "Aioun Branise" Saida Algeri. *Open Journal of Forestry*, 4 (5), 527-535. http://dx.doi.org/10.4236/ojf.2014.45057

Burra, S. (2020). Review on Bio-fertilizer Technology and Millet Production. *Agriculture and Environment*, 1 (4): 62-67. https://agrinenv.com/wp-content/uploads/2020/11/complete-issue-4-vol1-62-67.pdf

Chopra, V.L., Singh, R.B. and Varma, A. (1989). Crop productivity and sustainability-shaping the future. Proceedings of 2nd international crop science congress. Oxford and IBH publishing. New Delhi. 1111Pp. https://ci.nii.ac.jp/ncid/BA51523360

Christine, A.W., Reckling, M., Preissel, S., Bachinger, J., Bergkvist, G., Kuhlman, T., Lindström, K., Nemecek, T., Cairistiona, F.E.T., Vanhatalo, A., Zander, P., Murphy-Bokern, D. and Stoddard, F.L. (2017). Grain Legume Production and Use in European Agricultural Systems. *Advances in Agronomy,* 144, 235-303. https://doi.org/10.1016/bs.agron.2017.03.003.

CSA (Central Statistical Agency), (2018). Agricultural sample survey. 2014/2015 volume I Report on area and production of major crops. Statical Bulletin 578, May 2015, Addis Ababa.

EIAR (Ethiopian Institute of Agricultural Research) (2018). Faba bean Production Guideline Using Rhizobial Bio-fertilizer Technology. http://www.eiar.gov.et

Erana, K. (2020). Grain legumes production and productivity in Ethiopian smallholder agricultural system, contribution to livelihoods and the way forward. *Cogent Food & Agriculture*, 6 (1), 1722353. DOI: 10.1080/23311932.2020.1722353

Erana, K. and Zelalem, B. (2020). Expounding the production and importance of cowpea (*Vigna unguiculata* (L.) Walp.) in Ethiopia, *Cogent Food & Agriculture*, 6: 1769805. https://doi.org/10.1080/23311932.2020.1769805

FAO (Food and Agriculture Organization of the United Nations). (1990). Food Balance Sheets Database and FAO, Guidelines No. 70 for soil description. 3rd ed. FAO, Rome. *http://faostat.fao.org/*

FAO (Food and Agriculture Organization). (2019). FAOSTAT Statistical Database of the United Nations Food and Agriculture Organization (FAO) statistical division. Rome.

Fekede, G., Mideksa, B. and Asfaw, Z. (2018). On Farm Demonstration of Improved Varieties of Faba Bean (*Vicia faba* L.) in Gemechis, Chiro and Tullo Districts of West Hararghe Zone, Oromia National Regional State of Ethiopia. *Journal of Agricultural Extension and Rural Development,* 10 (9), 186-191. https://academicjournals.org/journal/JAERD/article-full-text-pdf/D02DB1B58431. DOI: 10.5897/JAERD2018.0967

Gebre-Egziabher, M., Hadush, T. and Fetien, A. (2014). Agronomic performance of some haricot bean varieties (*Phaseolus vulgaris* L.) with and without phosphorus fertilizer under irrigated and rain fed conditions in the Tigray and Afar regional states, northern Ethiopia. *Momona Ethiopian Journal of Science* (MEJS), 6 (2), 95-109. https://www.ajol.info/index.php/mejs/article/view/109712

Getachew T. (2019). Pulse crops production opportunities, challenges and its value chain in Ethiopia: A review article. *Journal of Environment and Earth Science*, 9 (1), 20-29. DOI: 10.7176/JEES

Heba, I.M., Mahmoud, R.S., Abdulwareth, A.A., Magdi, T.A., Abdul, B., Ahmed, R.S., Rafq, L. and Abou-El-Enain, M.M. (2021). Role of Microorganisms in Managing Soil Fertility and Plant Nutrition in Sustainable Agriculture. *Plant Growth-Promoting Microbes for Sustainable Biotic and Abiotic Stress Management*, 93-114. https://doi.org/10.1007/978-3-030-66587-6_4

James, R.F. (2000). Crop Productivity & Sustainability—Shaping the Future. Proceedings of 2nd International Crop Science Congress. https://doi.org/10.2135/cropsci2000.0016br

Janusz, P. (2022). Effect of Row Spacing and Plant Density on the Yield of (*Faba bean* L.) Under Very Differentiated Humidity Conditions. *Journal of Agricultural Science*, 14 (1); DOI:10.5539/jas.v14n1p1

Juliana, H.S., Cícero Célio de, F., Robélio, L.M., Beáta, E.M., Luiz E.C. B., Jader G.B., Diego Mendes de S. (2014). Methods of soil organic carbon determination in Brazilian savannah soils. *Science of Agriculture,* 71 (4), 302-308. http://dx.doi.org/10.1590/0103-9016-2013-0306

Kebede, K. (2020) Grain legumes production and productivity in Ethiopian smallholder agricultural system, contribution to livelihoods and the way forward. Cogent Food & Agriculture, 6 (1), 1722353. https://doi.org/10.1080/23311932.2020.1722353

Keeney, D.R. and Nelson, D.W. (1982). Nitrogen Inorganic Forms. In Page, A.L., et al., Eds., Methods of Soil Analysis, Part 2, Agronomy Monograph No. 9, ASA and SSSA, Madison, 643-698. - References - Scientific Research Publishing (scirp.org)

Kubure, T.E., Raghavaiah, C.V. and Hamza, I. (2016) Production Potential of Faba Bean (Vicia faba L.) Genotypes in Relation to Plant Densities and Phosphorus Nutrition on Vertisols of Central Highlands of West Showa Zone, Ethiopia, East Africa. *Advances in Crop Science and Technology*, 4, 214. DOI:10.4172/2329-8863.1000214

MoARD (Ministry of Agriculture and Rural Development). (2015). Crop variety register. Animal and Plant Health Regulatory Directorate, Issue No. 12. Addis Ababa, Ethiopia. 96–103Pp.

Mulugeta, A., Kassahun, T. and Kifle, D. (2015). The Importance of Legumes in the Ethiopian Farming System and Overall Economy: An Overview. *American Journal of Experimental Agriculture*, 7 (6), 347-358. DOI: 10.9734/AJEA/2015/11253

Muoni, T. (2019). Integrating legumes in mixed crop-livestock systems in East Africa: Farmers' perceptions, ecosystem services and support for decision making. Acta Universitatis Agriculturae Sueciae, 52, 1652-6880. https://pub.epsilon.slu.se/16308/7/muoni_t_190903.pdf.

Nataraja and Sons. (1960). Products and Services/ Trader from Madurai-India MART.

Nweke, I.A. (2018). In support of a well-planned intercropping system in southeastern soils of Nigeria: A review. African Journal of Agricultural Research, 13 (26), 1320–1330. DOI:10.5897/AJAR2017.12743.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. (2002). Laboratory Methods of Soil and Plant Analysis: A Working Manual; 2nd Edition. Sacred African Publishers, Nairobi, Kenya. (sciepub.com)

Osman, A.E., Ibrahim, M.H. and Jones, M.A. (1988). The Role of Legumes in the Farming Systems of the Mediterranean Areas. Proceedings of a Workshop on the Role of Legumes in the Farming Systems of the Mediterranean Areas UNDP/ICARDA, Tunis, June 20–24. SpringerLink. ISBN: 978-94-010-6949-6

Prakash, M. and Murugan, S. (2009). Legumes: Their Production, Improvement and Protection Kindle Edition. 378Pp. *Legumes: Their Production, Improvement and Protection, Prakash, M., Murugan, S. - Amazon.com*

Sajid, S., Ramírez-Bahena, M.H., Santillana, N., Zúñiga, D., Álvarez-Martínez, E., Peix, A., Mhamdi, R. and Velázquez, E. (2014). *Rhizobium laguerreae* sp. nov.nodulates *Vicia faba* on several continents. *International Journal of Systematic and. Evolutionary Microbiology,* 64, 242–247. DOI: 10.1099/ijs.0.052191-0.

Sameh, H.Y., Fayrouz, H., El-Megeed, A. and Saleh, A.S. (2017). Improvement of Faba Bean Yield Using Rhizobium/Agrobacterium Inoculant in Low-Fertility Sandy Soil. *Agronomy,* 7 (2), 1-12. Doi:10.3390/agronomy7010002

SAS (Statistical. Analysis System). (2009). SAS Version 9.3 © 2001–2002. Cary, NC: SAS Institute, Inc.

Tamirat, W. (2019). Effects of Nitrogen Fertilizer Rate and Inter-row Spacing on Yield and Yield Components of Teff [*Eragrostis teff* (Zucc.) Trotter] in Limo District, Southern Ethiopia. *International Journal of Plant & Soil Science*, 31 (3), 1-12. https://doi.org/10.9734/ijpss/2019/v31i330211

Tamirat, W. and Tilahun, N. (2020). The Response of Teff [*Eragrostis teff* (Zucc) Trotter] to Nitrogen Fertilizer Application and Row Spacing: A Review. *Advances in Life Science and Technology*, 78, 7-14. DOI: 10.7176/ALST/78-02

Teklay, A., Tsehaye, B., Yemane, N. and Assefa, W. (2014). Study on occurrence and importance of faba bean diseases with special consideration to the newly emerging "faba bean gall" in Tigray, Ethiopia. *African Journal of Agricultural Research*, 9 (50), 3627-3631. DOI: 10.5897/2013.8370

Tolera, A. and Zerihun, A. (2018). Effects of Fertilizer, Rhizobium Inoculation and Lime Rate on Growth and Yields Field Pea in Horro and Gedo Highlands. *Advances in Crop Science and Technology*, 6 (5), 1000397. DOI: 10.4172/2329-8863.1000397

Trishna, M., Surajit, B., Madhurankhi, G., Purnita, B., Bannhi, D., Abhrajyoti, G. and Prosun, T. (2016). Biofertilizers: a potential approach for sustainable agriculture development. A review Article. *Environmental Science Pollution Research,* 1-22. DOI 10.1007/s11356-016-8104-0

USDA Foreign Agricultural Service. (2018). Pulse crops market update (Vol. ET 1819). Addis Ababa, Ethiopia. Home | USDA Foreign Agricultural Service

Walkley, A. and Black, I.A. (1934). An examination of Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid titration method. *Soil Science,* 37, 29-38. DOI: 10.1097/00010694-193401000-00003

Yasin, G. and Esrael, K. (2017). Participatory on Farm Evaluations and Selection of Improved Faba Bean (*Vicia faba* L.) Varieties in Four Districts of South Ethiopia. *Advances in Crop Science and Technology,* 5 (4), 293. DOI: 10.4172/2329-8863.1000293

Yohannis, D., Kiros, H. and Yirga, W. (2015). Inoculation, phosphorous and zinc fertilization effects on nodulation, yield and nutrient uptake of Faba bean (*Vicia faba* L.) grown on calcaric cambisol of semiarid Ethiopia. *Journal of soil science and environmental management,* 6, 9-15. https://academicjournals.org/journal/JSSEM/article-full-text-pdf/C4EA15950114 DOI:10.5897/JSSEM/2013.0406