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Effects of Strains and Vermicompost Application on Growth and Yield Components of Faba Bean Under Greenhouse Condition

Gezahagn Goshu Abate

Department of Natural Resources Management, Wollo University, Dessie, Ethiopia

Email address:
gezahagn38@gmail.com, gezahagngoshu.27@gmail.com

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Abstract: Faba bean (Vicia faba L.) is one of the major leguminous crops grown in the world. However, the national average faba bean yield is very low compared to its potential yield in Ethiopia, particularly in north eastern Ethiopia due to lack of organic fertilizer and insufficient number of indigenous Rhizobium. To achieve this objective, this green house experiment was arranged in CRD with three replications in the factorial combination of three levels of rhizobium strains (non-inoculated, RS-17 and RS-1035) and four rates of vermicompost (0, 5, 10 and 15 ton/ha) treatments. It was carried out from October 2020 to May 2021 using Dosha faba bean. All growth and yield parameters data were given to the analysis of variance (ANOVA) using statistical analysis software version 9.4. The result showed that the main effect of rhizobium strains enhanced growth parameters (nodule number, symbiotic effectiveness, and number of leaves per plant) while improving total biomass yield. Whereas, the main effect of vermicompost rate were predominantly on yield parameters (number of productive piller, number of pod per plant, number of seed per pod, straw yield, total biomass yield) while improving plant height and number of leaves per plant. On the other hand, the interaction effect of rhizobium strains and vermicompost rate affected plant height, number of leaves per plant, number of seed per pod, straw yield, and total biomass yield. Treatments that received combined RS-17 and 15 ton/ha vermicompost provided the maximum plant height (79.3 cm), number of leaves (70.5), number of seeds (3.75), straw yield (191.6kg/ha) and biomass yield (5.686 ton/ha). This implies that combined application of vermicompost and using inoculated seed can improve productivity faba bean at smallholder farmers' level. Therefore, it is recommended to use integrated application of 15 ton/ha vermicompost and RS-17 inoculants to increase productivity of faba bean in the study area. Furthermore, the experiment should be supported by field studies on different area soils.

Keywords: Biomass Yield, Green House, Growth Parameters, Leguminous Crop, Yield Parameters

1. Introduction

Faba bean is one of the legumes being integrated into the smallholder farming systems to improve soil fertility through atmospheric nitrogen (N_2) fixation and increasing crop yield as crop rotation [19]. Nitrogen-fixation by rhizobia-legumes symbiosis play an important role in reducing the consumption of chemical fertilizers, increasing soil fertility, and eliminating the undesirable pollution impact of chemical fertilizers in the environment [20, 29]. Likewise, faba bean is a widely cultivated grain legume in many countries for food and feed purposes [1]; and is the leading protein source for the rural people used to make various traditional dishes [26]. Despite its multiple benefits of faba bean, its productivity remained very low compared to its potential yield both at national and regional level. This might be due to prevalence of pest and diseases, poor soil fertility, ineffective and insufficient number of indigenous *Rhizobium* in the soils [15, 16].

Faba bean seed inoculation with rhizobium strains reduces the required mineral nitrogen by 25%, environmental pollution, and degradation resulting from the application of chemical fertilizer [3]. Additionally, it increases supply of other nutrients such as phosphorus and iron, produces plant hormones, and enhances other beneficial bacteria or fungi [32]. In another way, during vermicomposting, earthworms physically fragment the substrate leading to new nutrient pools and large surface area which provides nutrients in forms that are readily taken up by the plants such as nitrates, exchangeable P, and soluble K, Ca, and Mg [9, 24].

Most farmers in the study area have been using huge amount of chemical fertilizers rather than incorporating organic sources of fertilizers. This action leads to the destruction of microorganisms in the soil, poor soil structure, less available plant nutrients, and reduce soil fauna-flora distribution [1]. Being these problems are continued, there are no sufficient studies conducted particularly on the effects of seed inoculation and vermicompost application on growth and yield parameters of faba bean at Gerado kebele, Dessie Zuria District. Therefore, this study was aimed to investigate the effects of Rhizobium strain and vermicompost rate on growth and yield of faba bean (*Vicia faba* L.) in Gerado kebele, Dessie Zuria District, North-Eastern Ethiopia as an evidence for sustainable soil management.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted from October 2020 to May 2021 under greenhouse conditions at Wollo University. The experimental soil was collected from Gerado kebele in Dessie Zuria District. Gerado kebele is geographically located at 11°15' 0"N of latitude and 39 ° 24' 0" E of longitude with ranges of altitude 2200 and 2800 meters above sea level (Figure 1).

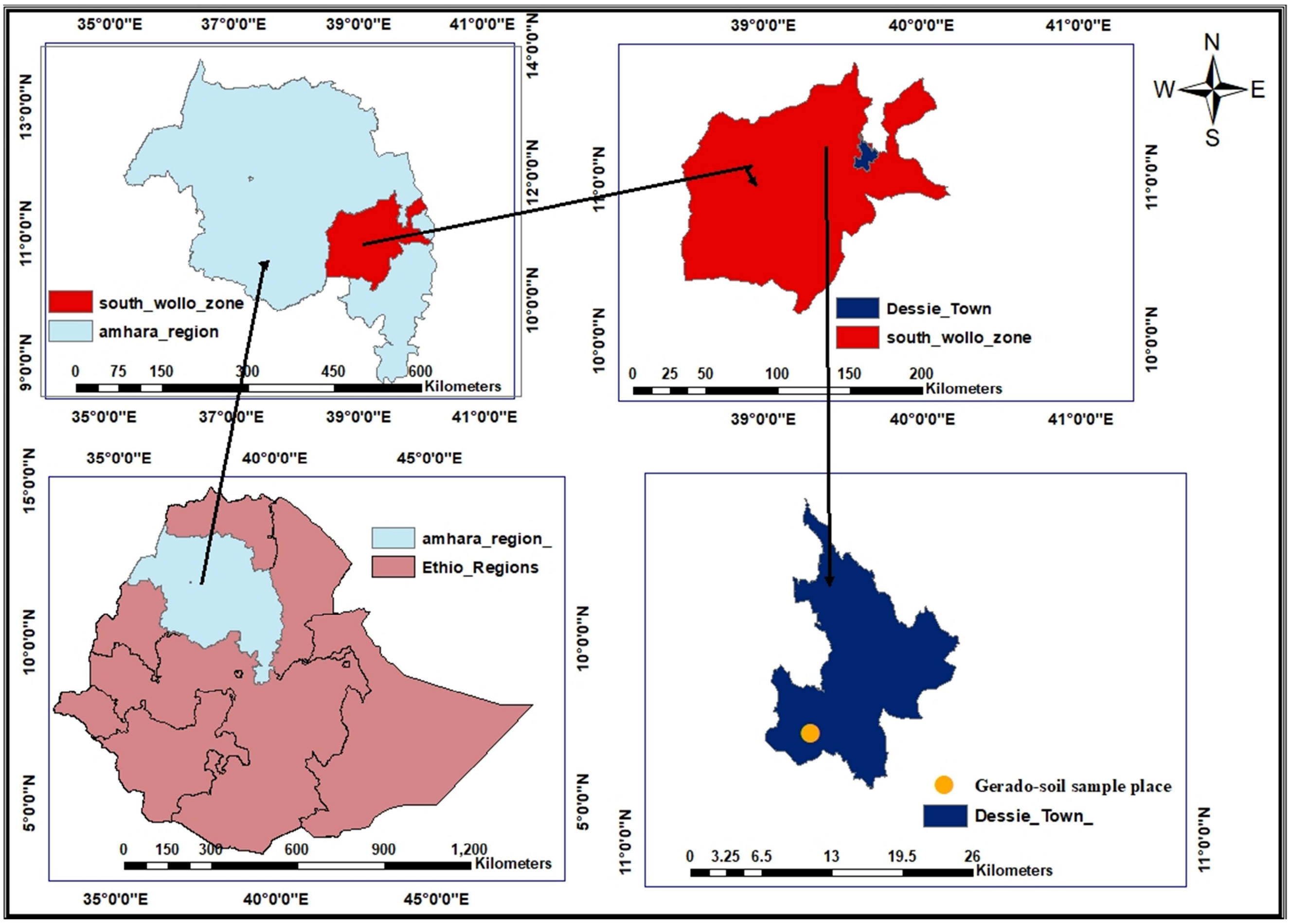


Figure 1. *Geographical map of the study area.*

The total annual rainfall of the area during 2019 was 1245 mm and the mean annual rainfall for 12 year (2008-2019) was 1085 mm per year. The area was characterized by a unimodal rainfall pattern that receives peak rainfall from mid of July to end of August. The monthly average minimum and maximum temperature was 2.9 °C and 28.5°C, respectively. The study area contains three agro-ecological zone distribution which covers; 8855.7 ha (9.89%) Woina Dega, 64067.9 ha (71.55%) Dega, and 16615.8 ha (18.56%) Wurch. The soil of study area was dominantly *Vertisols* (63%) while the remaining 25% and 12 % dominated by *Leptosols* and *Regosols,* respectively [31]. The district's farming system was characterized by mixed crop-livestock system that is carried on a subsistence scale. The major crops grown in the area were barley, wheat, bean, potato, teff, maize, peas, sorghum, and chickpea [11].

2.2. Experimental Materials

Improved faba bean seed variety, Dosha faba bean (COLL

155/00-3) was collected from Holeta Agricultural Research Centre (HARC). Dosha faba bean variety grows well on 1900-2800 masl altitude with 700-1000 mm rainfall and is moderately resistant to chocolate spot and rust [12].

The crop was grown in pot which perforated on the bottom side to drain excess water. The size of the pot was 40 cm in diameter and 35 cm height made of plastic locally named as *Baledi* which holds 20 liters water. Each pot had comparatively 1.256×10^{-5} ha in area coverage. Water requirement of the crop was supplied uniformly from drip irrigation. The experimental soil was *Vertisols* and characterized by high clay content, slightly dark in color and sticky character when wet [7, 31]. Vermicompost was fully decomposed by earth worms.

A fast growing *Rhizobium*, *leguminosarum biovar viceae* was used as bio-fertilizer. The *Rhizobium* strains (FB-1035 and FB-17) that released from HARC soil microbiology laboratory were used for seed inoculation at 500 g/ha rate. These strains have been proven to enhance the nodulation capacity, agronomic, and yield performance of faba bean under wide ecological conditions [1, 33]. Uniform triple-superphosphate (TSP) rate (100 kg/ha or 1.256 g per pot) was applied for the whole experimental units.

2.3. Treatments, Experimental Procedures, and Design

The factorial combinations of four rates of vermicompost (0, 5, 10 and 15 ton/ha) and three levels of Rhizobium strain (non-inoculated, inoculated with RS-17 and RS-1035 strains) treatments were laid out in CRD and replicated three times (Table 1).

The soil was obtained from different points of the farmer field from the top 0-30 cm soil depth. Sample soil was collected on large plastic sheets then mixed thoroughly and exposed to the sun. Coarser soil materials were crushed and sieved with plastic screens of 40 mm mesh. A drainage hole of about 1cm in diameter was made in the bottom of each pot. Twenty (20) kg/pots air-dried soil were being uniformly packed in plastic pots. All the pots were watered with equal amount of water to ensure uniform initial conditions for planting and germination.

A total of 36 pots were arranged in CRD with 4.5 m by 2 m (9 m^2) area in greenhouse. The space between replications and treatments was 0.5 m and 0.2 m, respectively and the pots were arranged in three rows and then five faba bean seeds planted in each pot at 8 cm depth on December 5, 2020.

The predetermined rates of vermicompost were incorporated into soil before one month of the crop sowing day. Vermicompost applications were rated on a dry-weight basis. Rhizobium inoculation was carried out during crop planting. At sowing, faba bean seeds were inoculated with predetermined rhizobium strain using sugar solution (10 g) for 100 ml of water as an adhesive agent and then, left to dry in the shade for minutes before planting as per [12] procedure. Weeds were controlled manually and all other remaining agronomic practices were properly practiced at given schedule. The crop was allowed growing for five months until the crop matured.

Table 1. *Treatment combinations of Rhizobium strains and vermicompost rate.*

Treatment number	Treatment combination	Treatment description
T1	RS_{0+} V_0	RS_0=un inoculated, V_0=0
T2	$RS_{0+}V_5$	RS_0= un inoculated, V_5=5
T3	$RS_{0+}V_{10}$	RS_0= un inoculated, V_{10}=10
T4	$RS_{0+}V_{15}$	RS_0= un inoculated, V_{15}=15
T5	RS-1035+V_0	RS-$_{1035}$= inoculated, V_0=0
T6	RS-1035+V_5	RS-$_{1035}$= inoculated, V_5=5
T7	RS-1035+V_{10}	RS-$_{1035}$= inoculated, V_{10}=10
T8	RS-1035+V_{15}	RS-$_{1035}$= inoculated, V_{15}=15
T9	RS-17+V_0	RS-$_{17}$= inoculated, V_0=0
T10	RS-17+V_5	RS-$_{17}$= inoculated, V_5=5
T11	RS-17+V_{10}	RS-$_{17}$= inoculated, V_{10}=10
T12	RS-17+V_{15}	RS-$_{17}$= inoculated, V_{15}=15

RS_0=Un-inoculated, RS-1035=Inoculated, RS-17=Inoculated, V_0=0, V_5=5 t/ha, V_{10}=10 t/ha and V_{15}=15 t/ha.

2.4. Data Collection

2.4.1. Nodule Count and Growth Parameters

Number of Nodules per Plant (NNP): The data was taken by counting the number of nodules from 2 randomly selected plants in each pot. Bulks of the root mass carefully uprooted from two randomly selected plants from each pot at 50% flowering. After the plants were uprooted gently, the root of faba bean plant was washed by tap water. Nodules remaining in the soil were picked by hand. Nodules attached to each plant root were also removed and separately spread on a sieve for some minutes until the water had drained from the surface of the nodule. The mean values of effective nodules from the two plants were recorded as total number of nodules per plant.

Number of Effective Nodule (NEN): Effective root nodules isolated based on their color (Pinkish and reddish color due to leg haemoglobin presence) and ineffective (green to white color) was counted in each two randomly selected plant. The color score was made in 1-4 scale as: 1= white and green (non- effective), 2=pink (moderately effective), 3= slightly dark red (effective) and 4= deep dark red (highly effective).

Nodulation Rating (NR)*:* Was estimated carefully uprooting two plants form each pot and examine for nodulation in the taproot, in the secondary roots but close to taproot, scattered all over the roots and plants showing no root nodulation. The rating of the plants for nodulation was done in scale of 1-10. The number of plants, which have developed nodules on taproot, close to taproot, scattered over the entire roots and plants with no nodules on their root were identified and subjected to the following formula for nodulation rating (NifTAL, 1979).

$$\text{Nodulation Rating} = \frac{(10\times \text{NPTRN}) + (5\times \text{NPNCTR}) + (1\times \text{PSN}) + (0\times \text{PNN})}{N}$$

Whereas, NPTRN = Number of plants with taproot nodulation

NPNCTR = Number of plants with nodules close to taproot

PSN = Number of plants with scattered nodulation

PNN = Number of plants without nodulation

N = Total number of plants

Symbiotic Effectiveness (SE): Plant dry matter was determined at mid flowering stage of the crop from plants sampled for nodulation. After the nodules had been collected from roots, the plant samples were placed in a labelled perforated paper bags and oven dried to a constant weight for 65 h at 75 °C to determine the plant dry matter. The average dry weight of two plants was measured to determine dry weight per plant. Finally, symbiotic effectiveness of faba bean strains was calculated based on the formula set by [27] as:

$$SE = \frac{\text{Inoculated plant DM}}{\text{Uninoculated plant DM}} \times 100\%$$

Where: - DM = dry matter in gram, SE = Symbiotic effectiveness (%)

The rate of nitrogen-fixing effectiveness is evaluated as highly effective if the value is greater than 80%, effective if it is between 50% and 80%, less effective if the values are between 35% and 49% and infective when the values are below 35%.

Number of Leaves per Plant (NLP): It was taken as the average number of leaves counted from two plants per pot. This was determined as the total number of leaves and recorded at 50% flowering stage of the crop.

Plant Height (PH): The average height of two plants per pot in each treatment measured from the soil level in the pot to top of the plants using a ruler at physiological maturity from ground to the tip of the main stem and then the mean was recorded as height per plant.

2.4.2. Yield and Yield Components

Number of Productive Tillers (NPT): It was recorded by counting the number of fertile (productive) tillers that arising from main stem (by counting all the tillers producing seeds) at pod setting stage.

Number of Pods per Plant (NPP): It was determined by taking the average number of pods counted from 2 randomly selected plants in all pots of each treatment at physiological maturity and the means were recorded as the number of pods per plant.

Number of Seeds per Pod (NSP): It was taken by counting the number of seeds from pods taken each plant per treatment at harvest and then the total number of seeds was divided by the total number of pods to get average number of seeds per pod.

Straw Yield (SY):-Straw yield was determined by subtracting the grain yield from total above ground biomass yield.

Total Biomass Yield (TBY kg/ha): It was estimated by measured the whole plant parts including steam, leaves, pods and grains from the net pot area using digital balance during maturity and express in kg/ha.

2.5. Data Analysis

The data collected from the experiment at different growth stages were subjected to statistical analysis (ANOVA) as per the experimental design using SAS version 9.4 and GenStat 12th edition. The mean separation was carried out using the least significant difference (LSD) test at P≤ 0.05. Interpretations were made following the procedure described by [18].

3. Results and Discussion

3.1. Effects of Rhizobium Strain and Vermicompost Rate on Nodule Count and Growth Parameters of Faba Bean

3.1.1. Number of Nodule Per Plant (NNP)

Number of nodule per plant was affected by the main effect of Rhizobium inoculants only; and it was statistically highly significant (P≤ 0.01). The highest number of nodules (166) was recorded from the rhizobium inoculants with RS-17 strain; and had statistical parity result with RS-1035 (160). However, the lowest nodule (122) was recorded from the control treatment (Table 2). The possible reason could be due to the fact that nitrogenase enzyme present in inoculants which introduced through infection causes nodule formation and rhizobacteria are competent bacteria in the rhizosphere that are able to multiply and colonize plant roots at all stages of plant growth.

In line with this result, [15] found that faba bean inoculation with EAL-108 strains produced the highest number of nodules (69.6) than inoculants with EAL-17 (63.8) and EAL-1035 (64.8) strains. [29] Also revealed that faba bean plants inoculated by NGB-FR-126 strain showed the highest number of nodules (152); and which was significantly greater than all other treatments, including the full N-fertilized treatment (142). In contrary to this result, [4] reported that application of 4-6 ton/ha vermicompost significantly increased the nodule number (294-302, 235-333) than inoculation with HUFBR-15 strains (219-289) in 2012 and 2013, respectively.

3.1.2. Number of Effective Nodule (NEN)

Effective and slightly effective nodule number per plant was affected by inoculation of Rhizobium strains; and it was statistically highly significant (P≤ 0.01). But non effective nodule number per plant significantly affected by inoculation of Rhizobium strains (P≤ 0.05). The highest numbers of effective (45) and slightly effective nodules (43) were obtained from the inoculated with RS-17 strain but the lowest effective and slightly effective nodules were recorded from un-inoculated (Table 2). The possible reason for this result could be inoculation of faba bean with rhizobium strain RS-17 can create high symbiotic association with the host plant. This result is supported by [15] who reported that inoculation of faba bean with rhizobium strain caused noticeable increase effective nodule per plant over un-inoculated treatment. [5] Also found that faba bean inoculation with *Degaga* variety significantly increased effective nodule, nodule fresh weight and nodule dry mass over control. Likewise, [7] reported that inoculation of NSFBR-15 to variety *Dosha* and TAL-1035 to variety *Gora* produced the highest number of effective nodule and nodule dry weight per plant This result disagreed with that of [14] who stated that the plants which were not inoculated with rhizobium (EAL-110), but treated with FYM, lime, and P formed effective nodules with a higher number as compared with plants inoculated and received the same treatment.

Table 2. *Main effect of inoculants strains on number of nodules and effectiveness of nodule.*

Strains	Number of nodule	Non-effective N fixation	Slightly effective N fixation	Effective N fixation
RS_0	121.8[a]	28.12[a]	30.94[a]	32.12[a]
RS-1035	160.6[b]	34.79[b]	41.85[b]	41.79[b]
RS-17	166.2[b]	35.12[b]	42.98[b]	45.0[b]
CV (%)	15.0	18.5	16.5	16.3
LSD (0.05)	18.9	5.1	5.4	5.5

LSD (0.05) = Least Significant Difference at 5%; and CV (%) =Coefficient of Variation
Means with the same letter (s) are not significantly different at 5% level

3.1.3. Nodule Rating (NR)

The analysis of variance indicated that nodulation rating is not significantly (P≥ 0.05) influenced by the main and interaction effects. This finding is similar with [5] who reported that Rhizobium isolated from north and south Gonder did not bring significant different on nodule rating. Because, *Rhizobium* colonized the upper rhizospheric portion of the soil and extended to the taproot and forming nodule, which has less probability to form scattered nodule.

3.1.4. Symbiotic Effectiveness (SE)

Based on [27] formula, inoculation of RS-1035 and RS-17 created high symbiotic association with the host faba bean than the existing strains in the soil. When we compare the two rhizobium strains, rhizobium strain (RS-17) was more effective than rhizobium strains (RS-1035) (Table 3). This result was supported by the finding of [15] who confirmed that the symbiotic effectiveness of inoculants of faba bean strains with EAL-17, EAL-1035, and EAL-1018 were highly effective. Similarly, [5] stated that inoculation of *Rhizobium* strain formed high symbiotic association with the host plants. Besides, [29] found that faba bean inoculation with NGB-FR 126 strain showed high symbiotic association with faba bean plant.

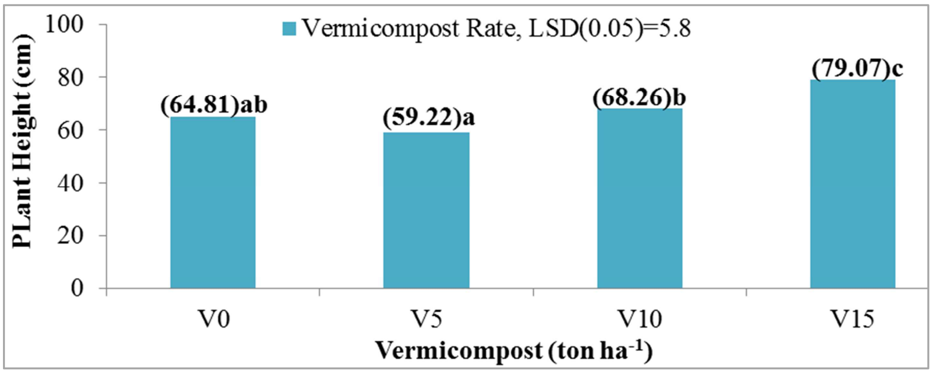
Table 3. *Main effect of inoculations on symbiosis effectiveness of faba bean.*

Strains	Plant Dry Weight	Percentage (%)	SE
Un-inoculated	265	___	___
RS-1035	233.043	88	HE
RS-17	246.445	93	HE

RS-rhizobium strains, HE-highly effective

3.1.5. Plant Height (PH)

Plant height was affected by the main effect of vermicompost and was statistically highly significant (P≤ 0.01). In agreement with this result, [4] reported that a remarkable increase in plant height of faba bean. They revealed that increasing vermicompost application with the highest values recorded at 8 ton/ha than the inoculated (*Rhizobium* strain, HUFBR-15) and control.



Labels in the same designs followed by the same letter are not significantly different at P≤ 0.05.

Figure 2. *Plant height affected by main effect of vermicompost application rate.*

Considering the interaction effect of Rhizobium strains and vermicompost rate, the longest plant height (79.3cm) was recorded from the treatment received combined 15 ton/ha vermicompost and RS-17. The interaction effect of Rhizobium strain and vermicompost affected plant height significantly (P≤ 0.05). Similarly, [6] stated that the highest plant height (77.52cm) of soybean was recorded on the plot treated with maximum rate of vermicompost with nitroxin-biofertilizer over control treatment.

Also, [14] found that the highest plant height (59.33 cm) of faba bean was obtained in the pot that received 8 ton/ha FYM combined with *Rhizobium* inoculants than control and other treatments.

Table 4. *Plant height affected by interaction effect of inoculant strains and vermicompost rate.*

Vermicompost rate (ton/ha)	Rhizobium strain		
	RS_0	RS-1035	RS-17
0	50.75^{a}	68.33^{cd}	75.33^{def}
5	60.83^{bc}	58.90^{abc}	57.92^{ab}
10	67.50^{bcd}	68.78^{cde}	68.50^{cd}
15	78.65^{ef}	79.22^{f}	79.33^{f}
CV (%)	8.8		
LSD (0.05)	10.1		

LSD (0.05) = Least Significant Difference at 5%; and CV (%) =Coefficient of Variation
Means with the same letter (s) are not significantly different at 5% level

3.1.6. Number of Leaves Per Plant (NLP)

The main effect of vermicompost and their interaction effects on the numbers of leaves per plant was highly significant (P≤ 0.01); whereas the main effect of inoculants strain was significant (P≤ 0.05). Maximum number of leaves (66.67) on each plant was recorded with maximum rate of vermicompost but minimum number of leaves (50.5) obtained from minimum rate of vermicompost (Figure 3). The increased number of leaves with increasing vermicompost application might be vermicompost contains most nutrients in plant available forms such as nitrates (NO_3^-), phosphates ($H_2PO_4^-$ and HPO_4^{2-}), soluble potassium (K^+), and magnesium (Mg^{2+}) and calcium'(Ca^{2+}) [23]. In line with this result, [14] stated that sole application of 8 ton/ha FYM was highly increased number of leaves per plant as compared with sole rhizobium inoculant and control plot.

With respect to faba bean inoculation, RS-1035 strains produced maximum number of leaves (59.75) which is statistically in par with RS-17 while the lowest number of leaves (55) recorded on un-inoculated pot (Figure 3). It might be due to the fact that *Rhizobium* inoculation improved the vegetative growth of plants under higher N by biological nitrogen fixer availability and the fact that faba bean produces most of its leaves during the early vegetative growth period when there was high soil N or effective nodulation. The study of [8] confirmed that inoculated plants produced 17% more leaves as compared to sole application of different rates of potassium fertilizer (30 and 60 kg/ha) and un-inoculated plants.

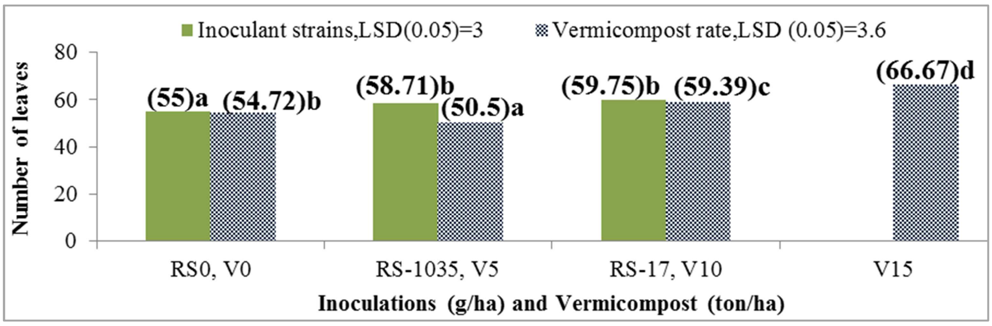


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Figure 3. *Number of leaves affected by main effect of vermicompost rate and inoculation.*

Table 5. *Interaction effect of inoculants strain and vermicompost on number of leaves per plant.*

Vermicompost rate (ton/ha)	Rhizobium strain		
	RS_0	RS-1035	RS-17
0	42.67^{a}	61.83^{de}	59.67^{d}
5	53.33^{bc}	50.17^{b}	48.0^{ab}
10	61.67^{de}	59.83^{d}	56.67^{cd}
15	62.33^{de}	67.17^{ef}	70.5^{f}
CV (%)	6.3		
LSD (0.05)	6.2		

LSD (0.05) = Least Significant Difference at 5%; and CV (%) =Coefficient of Variation
Means with the same letter (s) are not significantly different at 5% level

Concerning their interaction effects, the highest numbers of leaves per plant (70.5) was obtained in the pots that received maximum rate of vermicompost together with inoculants RS-17 and RS-1035 strains. But, lowest number of leaves (42.67) recorded on the control pot (Table 5). This implies that application of rhizobia with balanced organic fertilizers responded better to increase faba bean growth and development as compared to the control treatments. It might be due to stimulated biological activities in the presence of balanced nutrient supply [10]. Similarly, [13] stated that faba bean *Rhizobial* inoculation integrated with maximum application of compost produced maximum number of leaves than the control treatment.

3.2. Effects of Rhizobium Strain and Vermicompost Rate on Yield and y Yield Parameters of Faba Bean

3.2.1. Number of Productive Tillers (NPT)

The numbers of productive tillers were significantly (P≤ 0.05) affected by the main effects of vermicompost rate. The highest numbers of productive tillers (4) were observed in the pots received 15 ton/ha vermicompost while the lowest number of productive tillers recorded on the control pot (Table 6). It is due to the fact that vermicomposting contains sufficient amount of vitamins, amino acids, antibiotics, enzymes, and hormones directly used as food sources for crops. Consequently, increase in number and size of growing cells; and finally resulting in increased number of tillers [21]. The increment in number of productive tillers per plant might also be due to the presences of plant available form of P and

N in vermicompost [28]. In line with this result, [24] reported that a significant increase in number of productive tillers and number of shoot branches were observed with sole and combined application of vermicompost.

3.2.2. Number of Pods Per Plant (NPP)

NPP was significantly affected (P≤ 0.05) by the main effect of vermicompost rate. The maximum number of pods (17) was recorded from the pots received 15 ton/ha vermicompost while minimum pods on each plant (10) were obtained at control pot (Table 6). The increment in number of pods as the result of vermicompost application might be due to plentiful rhizospheric bacteria. These bacteria stimulates plant growth directly by solubilizing nutrients, production of growth hormone that improve soil aggregates, water holding capacity, and efficiency in atmospheric nitrogen fixation [30].

Besides, [6] found that application of maximum rate of (10 ton/ha) vermicompost significantly increased number of pod per plant (26.43) than seed inoculation by nitroxin biofertilizer (24.8) and control (21.6) in soybean. Likewise, [25] stated that the maximum number of pods (11) was recorded in plots receiving 5 ton/ha manure while minimum pods on each plant (9) was observed at zero level manure.

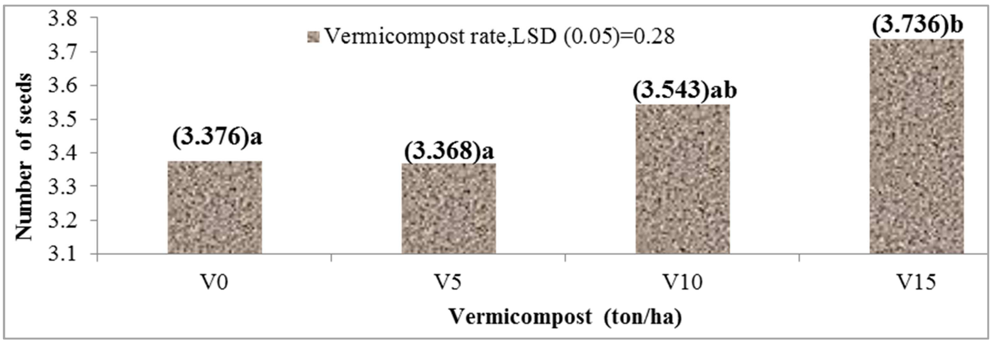
Table 6. *Main effect of vermicompost rate on number of productive tillers and number of pods per plant.*

Vermicompost rate (ton/ha)	Number of productive tillers	Number of pods
0	2.556^{a}	10.78^{a}
5	2.889^{ab}	13.11^{ab}
10	3.556^{bc}	16.00^{bc}
15	4.00^{c}	17.00^{c}
CV (%)	28.6	26.4
LSD (0.05)	0.9	3.7

LSD (0.05) = Least Significant Difference at 5%; and CV (%) =Coefficient of Variation
Means with the same letter (s) are not significantly different at 5% level

3.2.3. Number of Seeds Per Pod (NSP)

Number of seed per pod was significantly affected (P≤ 0.05) by the main effect of vermicompost rate and their interaction effect. The highest number of seeds per pod (3.736) was observed in the pots treated with 15 ton/ha while the lowest number of seeds per pod (3.368) was obtained from the pots treated with 5 ton/ha vermicompost (Figure 4).



Labels in the same designs followed by the same letter are not significantly different at P≤ 0.05.

Figure 4. *The main effect of vermicompost rate on number of seeds per pod.*

Combined use of 15 ton/ha vermicompost and RS-17 inoculant strain produced significantly higher number of seeds per pod. However, the lowest number of seeds per pod obtained from control pot (Table 7). The seed number increment with inoculation and vermicompost application might be due to the contribution of inoculation and organic fertilizer to each other in order to reach the state of optimal nutritional balance suitable for the growth and development of the plant.

In line with this result, [4] found that integrated use of high-quality vermicompost and Rhizobium inoculation significantly increased number of seeds per pod over control treatment. [6] Also reported that number of seeds per plant was recorded from seed inoculation with nitroxin combined with 10 ton/ha vermicompost treatments while the lowest number of seeds was recorded from control treatment. Similarly, [23] reported that the use of phosphate solubilizing bacteria and one strain of *Rhizobium* bacteria in combination with vermicomposting in faba bean plants increased number of seeds per pod over control plot.

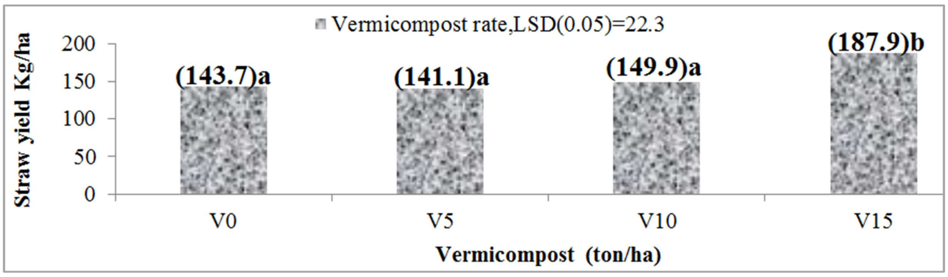
Table 7. *The interaction effect of inoculation and vermicompost rate on number of seeds per pod.*

Vermicompost rate (ton/ha)	Rhizobium strain		
	RS_0	RS-1035	RS-17
0	2.750^{a}	3.750^{c}	3.627^{c}
5	3.130^{ab}	3.553^{bc}	3.420^{bc}
10	3.710^{c}	3.460^{bc}	3.460^{bc}
15	3.747^{c}	3.710^{c}	3.750^{c}
CV (%)	8.2		
LSD (0.05)	0.49		

LSD (0.05) = Least Significant Difference at 5%; and CV (%) = Coefficient of Variation
Means with the same letter (s) are not significantly different at 5% level

3.2.4. Straw Yield

The straw yield was affected by the main effect of vermicompost rate; and it was statistically highly significant (P≤ 0.01). The interaction of vermicompost and inoculants strain significantly (P≤ 0.05) affected straw yield. Highest straw yield (187.9 kg/ha) was recorded in the pots treated with 15 ton/ha vermicompost while the lowest straw yield (141.1 kg/ha) was obtained from the pots which received 5 ton/ha vermicompost rate which was statistically parity with V_0 and V_{10} (Figure 5). Similarly, [17] reported that maximum straw yield of faba bean were obtained from FYM and P treated soils in comparison to control plot. [25] also stated that straw yield of faba was highly affected (P≤ 0.01) by manure application. Thus, the highest straw yield (1607 kg/ha) was observed at maximum rate of (5 ton/ha) manure.



Labels in the same designs followed by the same letter are not significantly different at P≤ 0.05.

***Figure 5.** The main effect of vermicompost rate on straw yield.*

From their interaction effect, the highest straw yield (191.6 kg/ha) was obtained from integrated use of RS-17 strain with 15 ton/ha vermicompost (Table 8). This might be probably due to stimulated biological activities in the presence of balanced nutrient which was supplied from the decomposition of vermicompost. This implies that application of *rhizobia* with balanced organic fertilizers responded better to increase faba bean straw yield.

***Table 8.** Interaction effect of inoculant strains and vermicompost rate on straw yield of faba bean.*

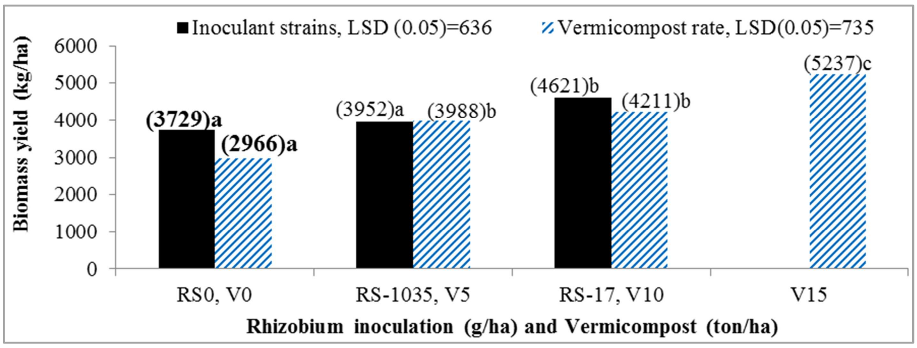
Vermicompost rate (ton/ha)	Rhizobium strain RS$_0$	RS-1035	RS-17
0	104.4^{a}	156.9^{cde}	169.7^{cde}
5	154.8^{cde}	152.6^{bcd}	116^{ab}
10	155.1^{cde}	151.3^{bc}	143.2^{bc}
15	181.4^{cde}	190.8^{de}	191.6^{e}
CV (%)	14.7		
LSD (0.05)	38.6		

LSD (0.05) = Least Significant Difference at 5%; and CV (%) =Coefficient of Variation
Means with the same letter (s) are not significantly different at 5% level

In agreement with this result, [2] reported that combined use of *rhizobia* inoculants with 6 t/ha vermicompost and 60 kg/ha NPSB rate significantly increased straw yield (125.86g/pot) of faba bean as compared to sole and control treatments. [33] Also stated that integrated use of rhizobium inoculation with 5 ton/ha compost and (150 kg/ ha) NPSB fertilizer significant increased straw yield of faba bean.

3.2.5. Total Biomass Yield (TBY)

The main effect of vermicompost rate and seed inoculation interaction effect on total biomass yield was highly significant (P≤ 0.01) while the main effect of Rhizobium strains was significant (P≤ 0.05). Considering the main effect, seed inoculation of faba bean with RS-17 strain gave maximum (4621 kg/ha) biomass yields while the lowest total biomass yield was obtained from control treatment (3729 kg/ha) which was statistically pair with (3952 kg/ha) RS-1035 strain. The highest total biomass yield (5237 kg/ha) was obtained in the pots received 15 ton/ha vermicompost but minimum total biomass yield was obtained from the pots supplied with zero rate vermicompost (Figure 6). In line with this result, [15] reported that inoculation of faba bean with EAL-1018 strain gave maximum (10.277 ton/ha) biomass yield than EAL-1035 (9.361 ton/ha) and EAL-17 (8.329 ton/ha) while the lowest biomass yield was obtained from the control treatment (7.327 ton/ha). [22] Also stated that total biomass of the three legumes, namely bush bean, winged bean, and yard long bean were significantly increased with application of (20%) vermicompost than control treatments.



Labels in the same designs followed by the same letter are not significantly different at P≤ 0.05.

***Figure 6.** Main effect of inoculations and vermicompost rate on total biomass yield.*

Regarding the interaction effects, maximum total biomass yield was obtained from combined use of 15 ton/ha vermicompost in combination with RS-17 strain but it had statistical parity with V_0+RS-17 and V_{15}+RS0 (Table 9). This increment in total biomass yield from combined application of vermicompost and inoculation might be due to the presence of high N derived from biological nitrogen fixer and vermicompost decomposition; resulted to optimal absorption of water, nutrients, and production plant growth hormones which increases qualitative and quantitative growth of the plant and thereby increased total biomass yield of the crop.

Table 9. *The interaction effect inoculation and vermicomopst rate on total biomass yield (Kg/ha) of faba bean.*

Vermicompost rate (ton/ha)	Rhizobium strain		
	RS_0	RS-1035	RS-17
0	1987^{a}	4962^{de}	5685^{e}
5	2984^{ab}	2829^{ab}	3086^{abc}
10	4260^{cd}	3679^{bc}	4026^{bcd}
15	5685^{e}	4338^{cd}	5686^{e}
CV (%)	18.4		
LSD (0.05)	1273		

LSD (0.05) = Least Significant Difference at 5%; and CV (%) =Coefficient of Variation

Means with the same letter (s) are not significantly different at 5% level

In agreement with this result, [33] found that integrated application of lime, compost, and rhizobia gave many fold enhancements in faba bean dry matter yield over control plot. [13] Also reported that the highest total dry biomass (4.165 ton/ha) was recorded in the plot received combination of 8 ton/ha FYM, 30 kg/ha P fertilizers with Rhizobium inoculation over single application this treatments as well as untreated plots.

4. Conclusion

The result of this finding showed that the main effect of rhizobium strains enhanced growth parameters (nodule number, symbiotic effectiveness, and number of leaves per plant) while improving total biomass yield. Whereas, the main effect of vermicompost rate were predominantly on yield parameters (number of productive tiller, number of pod per plant, number of seed per pod, straw yield, total biomass yield) while improving plant height and number of leaves per plant. On the other hand, the interaction effect of rhizobium strains and vermicompost rate affected plant height, number of leaves per plant, number of seed per pod, straw yield, and total biomass yield. Treatments that received combined RS-17 and 15 ton/ha vermicompost provided the maximum plant height (79.3 cm), number of leaves (70.5), number of seeds (3.75), straw yield (191.6kg/ha) and biomass yield (5.686 ton/ha). From this result we can conclude that, combined application of vermicompost and using inoculated seed can improve growth and yield of faba bean at smallholder. farmers' level. Therefore, farmers of the study area are advised to use combined application of 15 ton/ha vermicompost and RS-17 inoculants to increase productivity of faba bean at their farm land. Furthermore, the experiments should be supported by field studies on different area soils.

Data Availability

The data used to support the results of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there have no conflicts of interest.

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