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THE CO-APPLICATION OUTCOMES OF AN ELITE RHIZOBIUM INOCULANT AND VERMICOMPOST ON THE SOIL, AGRONOMIC AND ECONOMIC OUTPUTS OF FABA BEAN (*VICIA FABA L.*) IN THE CASE OF SEBETAHAWASE DISTRICT, CENTRAL HIGHLANDS OF ETHIOPIA

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This research sought to investigate how the yields of faba beans in farm settings in the Ethiopian district of SebetaHawase were affected by the co-application of an elite *Rhizobium* inoculant and vermicompost (VC). The study was conducted during the 2019/20 and 2020/21 cropping seasons. A randomized complete block design with three replications was used. After two years of data analysis, the average result revealed a significant ($P < 0.05$) variation in all parameters among the treatments in the district. In the SebetaHawase district, rhizobial isolates FB-17 + 0.76 ton ha^{-1} of VC and FB-17 + 0.57 ton ha^{-1} of VC showed relative first and second superiority in terms of total nitrogen content (%), available phosphorus (ppm), and organic carbon (OC %). At SebetaHawase, the treatments with the highest mean grain yield (3349, 2873 and 2746 kg ha^{-1}) was obtained with FB-17 + 0.76 ton ha^{-1} VC, FB-17 + 0.57 ton ha^{-1} VC, and FB-17 + 0.38 ton ha^{-1} VC. However, based on the findings of the partial budget analysis, the treatments FB-17 and FB-17 + 0.76 ton ha^{-1} VC at SebetaHawase had higher marginal rates of return (42848 and 1083% each). To identify the best alternative bio-organic fertilizers for faba bean production in Ethiopia's Pellicvertisol zones, these treatments are believed to be excellent candidates for additional testing in farmers' fields across a range of agro-ecologies.

Keywords: biological yield, economic yield, FB-17, N-equivalence, vermicompost

INTRODUCTION

Vicia faba L., or faba bean, is one of the most widely grown highland pulse crops in Ethiopia's colder highlands (CSA, 2018 and Getachew et al., 2019). Faba bean is mostly utilized as human food and as an animal feed source due to its high protein, mineral, vitamin, and fiber content (CSA, 2019/20). Additionally, when faba bean coexists harmoniously with rhizobia, they bring significant amounts of reduce form of nitrogen (N) to the soil environment (Sabrine et al., 2014). Major faba bean-producing nations' average grain yield (GY; 3.7 t ha^{-1}) were 40% higher than Ethiopia's national average (2.2 t ha^{-1}) of the same crop (FAOSTAT, 2017 and Mulugeta and Abere, 2021). They have identified several biological and non-biological issues that contribute to this low productivity, such as diseases, weeds, and inadequate rhizobium in the soil, in addition to soil acidity and low nutrient availability.

Faba bean grows in the highlands of Ethiopia are characterized by high rainfall, poor soil fertility, and acidified soil. In such poor ecosystems, the application of high levels of chemical fertilizers is becoming a customary practice to subsidize N and phosphorus (P) insufficiency, which are inaccessible, unaffordable, have low use efficiency, and are environmentally unfriendly (Mulugeta and Abere, 2021 and Bekalu et al., 2022). Thus, there has been growing attention to cost-effective, locally available, and eco-friendly sustainable agricultural practices such as biological and organic fertilizer technology alternatives that practically improve soil fertility, health, and crop productivity, including faba bean (Mulugeta and Abere, 2021).

One of the alternative technologies that significantly contribute to reducing the need for chemical N fertilizers, cutting production costs, and removing the unfavorable environmental pollution caused by chemical fertilizers is biological fertilizer sources, primarily rhizobia inoculation (Mahmud et al. 2021). It is predicted that nodulated legumes, such as pulses and oilseed legumes, fix N and add 21.45 Tg N to worldwide agricultural systems each year (David et al., 2008 and Mahmud et al. 2021). Other alternative fertilizer technologies that have gained attention in sustainable agricultural production include organic fertilizer sources like vermicompost (VC); the casting of earthworms, which has a low C: N ratio, high porosity, aeration, drainage, water holding capacity, microbial activity, and is rich in major macronutrients (N 2–3%, K 1.85–2.25%, and P 1.55-2.25%), micronutrients, plant growth hormones, enzymes, and plant protection from pests and diseases. The yield enhancement effect of rhizobial inoculation on faba beans is the focus of numerous practical works conducted in Ethiopia; however, little or no information regarding the biological and economic yield enhancement impact, as well as the soil conditioning potential of rhizobia VC integration, is available.

Thus, the purpose of this activity is to investigate how the co-application of elite rhizobium inoculant FB-17 and VC work together to increase faba bean's agronomic and economic yields, and soil conditioning potential in Ethiopia's central highlands, namely in SebetaHawase district.

MATERIALS AND METHODS

1. Field Experimental Sites

During the main cropping seasons of 2019/20 to 2020/21, the field experiment was carried out in the district of SebetaHawase. For the previous five years, these experimental sites had no history of rhizobial inoculation. The latitude and longitude of Sebeta Hawas are 8° 44' 59.99" N and 38° 39′ 59.99″ E, respectively, and their average elevation ranges from 1700 meters above sea level to around 3385 meters. The district receives an average of 21.5 °C of annual temperature and 1033 mm of rainfall annually (Abebe, 2006). Pellicvertisol, which has slightly acidic to mildly alkaline properties, predominated in the testing sites in this district. In the experimental sites, faba beans, tef, and wheat are the most often produced crops.

2. Elite Rhizobial Inoculant and Vermicompost (VC) Sources

The Holeta Agricultural Research Center's Biological and Organic Soil Fertility Management Research Program provided an elite faba bean rhizobial inoculant (FB-17) and VC, which had a total nitrogen content (TN) of 2.37% in wet weight basis. Holeta Agricultural Research Center is situated 29 kilometers from Ethiopia's capital city at 9.0581°N, 38.5049°E, at an elevation of 2400 meters above sea level.

3. Treatments and Experimental Design

Five treatments; FB-17, 100% N from VC; 0.76 ton ha^{-1}, FB-17+ 50% N from VC; 0.38 ton ha^{-1}, FB-17 + 75% N from VC; 0.57 ton ha^{-1}, and FB-17+ 100% N from VC; 0.76 ton ha^{-1} were evaluated under the pellicvertisol condition of SebetaHawase district against 18 kg N ha^{-1} (positive control or standard) and no FB-17 and no VC (untreated or negative control). The experiments were laid out in a randomized complete block design (RCBD) with three replications on a plot size of 4 m x 3 m. To reduce cross-contamination of treatments, the space between plots and blocks was enlarged to 0.5 and 1 m, respectively, and un-inoculated treatments were planted before inoculated treatments. The space between plants and rows was 10 and 40 cm, respectively. All the experimental plots received a basal application of 20 kg P ha^{-1} at the time of planting.

The positive control received 18 kg N ha^{-1} from urea at the time of planting. However, the negative control did not receive any form of external N source. The planting material was the Tumsa variety planted at 200 kg ha^{-1}. The experimental fields and experimental units were managed as per the recommended agronomic practices for faba beans.

4. Application of Vermicompost (VC) to the Soil

N equivalent base (0.76 ton ha^{-1}), (0.57 ton ha^{-1}, and 0.38 ton ha^{-1}) were used to weigh well-prepared VC in order to represent the 100%, 75%, and 50% N contents of VC, respectively. Each weighed bag containing the VC was stuck down in a polyethylene plastic bag, and a representative percentage was written on it with a permanent marker. Integrated portions of the VC in each treatment were added uniformly to each row of the plots before swinging the inoculated seeds.

5. Seeds Dressing

Carrier-based rhizobial inoculants were applied at a rate of 1000 g ha^{-1}. About 0.2 kg of faba bean seed was weighed, moistened with sticker solution and table sugar solution, and dressed carefully with the respective inoculant until all the seeds in plastic bags were uniformly coated. The whole seed dressing procedure was carried out under the shade. The fully-dressed and air-dried seeds were planted and immediately covered with soil.

6. Soil Sample Analysis

A combination of soil samples was composed of random spots of the trial plots at a depth of 0–30 cm just during the trial field arrangement. The soil samples were air-dried and ground to pass through a 2 mm sieve. Soil pH was measured in a 1:2.5 soil-to-water ratio. The wet digestion method was used to determine soil organic carbon (OC) (Walkley and Black, 1934). The TN content of the soil was determined by the wet-digestion procedure (Kjeldahl, 1883). The available P was determined by the Bray-II extraction method.

7. Data Collected and Yield Determination

Soil, agronomic, and economic data were collected and analyzed to determine the top-performing treatments in the SebetaHawase district of Ethiopia. The parameters were soil pH, available P, OC, TN, above-ground biomass yield (AGBY), GY, Haulm yield (HY), marginal net benefit (MNB), and marginal rate of return (MRR). The collected data were subjected to analysis of variance by the Statistical Analysis System (SAS) version 9.3 (2002). Means were compared with the Least Significance Difference (LSD) at a 5% probability level (SAS, 2002).

8. Economic Analysis

To compute the economic advantage of the intervention, farm prices of inputs and outputs were considered and the marginal rate of return (% MRR) was worked out for each treatment. Values≥100 were set as profitable in absolute terms (CIMMYT, 1988).

RESULTS AND DISCUSSION

1. Chemical Characteristics of Experimental Site

The soil's chemical properties were found similar among the experimental sites in SebetaHawase district (Table 1). The soil mean pH of the trial locations was 7.5. Therefore, trial sites were grouped in the ratings of slightly alkaline conditions (Tekalign et al., 1991). The mean of OC, available P and TN contents of the trial sites were 1.21%, 9.8 ppm and 0.08%

respectively. The mean OC, available P and TN contents of the trial locations were found in low ratings (Tekalign et al., 1991).

Table (1). Major chemical properties of the experimental sites before planting.

Parameter	SebetaHawase (average)	Range	Test Method
pH	7.5	7.4-8.5	1:2.5 H_2O
TN (%)	0.08	0.06-0.09	Modified Kjeldhal
Available P (ppm)	9.8	7.9-11.6	Bray II
OC (%)	1.21	1.13-1.29	Walkley and Black (1934)

Table (2) shows the combined effects of an elite rhizobium inoculant and VC on pH, TN (%), available P (ppm), and OC % following planting. The accompanying table demonstrates that the rhizobium- VC treatments relatively decreased the average soil pH in the district when compared to the negative and positive controls. The creation of certain organic acids as a consequence of breakdown and increased microbial activity during the decomposition of VC in the presence of rhizobia may be the reason of this. This result is in line with studies by Edwards (2004), Margit (2016) and Asrat et al. (2023).

Table (2). The combined effect of an elite rhizobial inoculant and vermicompost (VC) on some soil chemical properties after planting in 2019-2021 growing seasons.

Treatment	SebetaHawase (average)			
	pH	TN (%)	Available P (ppm)	OC (%)
No inoculation	7.87	0.05	6.5	0.77
Recommended N	7.85	0.073	8.3	1.12
FB-17	7.57	0.079	13	1.03
0.76 ton ha^{-1} VC	7.66	0.083	8.3	1.13
FB-17 + 0.38 ton ha^{-1} of VC	7.69	0.076	7.9	1.04
FB-17 + 0.57 ton ha^{-1} of VC	7.77	0.084	8.4	1.13
FB-17 + 0.76 ton ha^{-1} of VC	7.79	0.085	8.9	1.14

In both districts, all soil parameters showed a numerical increase after planting in comparison to the negative controls, as indicated by the results presented in Table (2). Rhizobia and VC have qualities that improve the soil's active chemical and biological qualities and release nutrients and materials when microorganisms break down the compost, which increases the availability of micro and macronutrients, growth promoters, enzymes, hormones, and other elements (Hossein and Mohammad, 2014). Table (2) above shows that in the district treatments (FB-17 + 0.76 ton ha^{-1} of VC) and (FB-17 + 0.57 ton ha^{-1} of VC) demonstrated relative first and second superiority in TN (%), available P (ppm) and OC (%). These outcomes were consistent with the findings of Manivannan et al. (2009) and Asrat et al. (2023). In comparison to the negative control at SebetaHawase district, the aforementioned treatments shown increases in N (%), available P (ppm), and OC (%) of 94, 27 and 32%, and 40, 23 and 32%, respectively.

2. Response of Faba Bean Yield to Rhizobium Inoculant and Vermicompost (VC) at SebetaHawase Districts in 2019-2021

The collective analysis of the two years of data at SebetaHawase portrayed that there was significant ($P \leq 0.05$) variation among the treatments and years on all parameters (Table 3). Except treatments (Negative control and Recommended N+), which showed statistically the least AGBY (2849 kg ha^{-1}) and (4255 kg ha^{-1}), respectively, no statistically significant differences were found among the treatments. Treatments (FB-17+ 0.76 ton ha^{-1} of VC) and (FB-17+ 0.57 ton ha^{-1} of VC) had the highest AGBY scores (5479 kg ha^{-1}) and (5224 kg ha^{-1}), respectively. AGBY increases of 48, 22, 45 and 18% above the negative and positive controls, respectively, were seen in the aforementioned treatments.

Table (3). Response of Faba bean yield to rhizobial inoculants and vermicompost (VC) at SebetaHawase district in 2019-2021 growing seasons.

Treatment	AGBY (kg ha^{-1})	GY (kg ha^{-1})	HY (kg ha^{-1})
Negative control	2849c	2084d	2283d
Recommended N+	4255b	2531bcd	2526d
FB-17	4737ab	2306cd	3559b
0.76 ton ha^{-1} VC	4831ab	2308cd	3198bc
FB-17 + 0.38 ton ha^{-1} VC	4789ab	2746bc	2827cd
FB-17 + 0.57 ton ha^{-1} VC	5224a	2873b	3597b
FB-17 + 0.76 ton ha^{-1} VC	5479a	3349a	4405a
LSD (P<0.05)	909	457	558
Year			
SebetaHawase (2019/20)	5150a	3757a	4421a
SebetaHawase (2020/21)	4097b	1442b	1978b
LSD (P<0.05)	486	244	298
CV (%)	16	15	15
Mean	4674	2600	3199

AGBY= above ground biomass yield at maximum maturity, GY= grain yield, HY= Haulm yield, VC= vermicompost.

The treatment with the greatest statistical score, FB-17+ 0.76 ton ha^{-1} of VC, produced GY 3349 kg ha^{-1}. The second and third highest GYs (2873 kg ha^{-1}) and (2746 kg ha^{-1}) were obtained by treatments (FB-17+ 0.57 ton ha^{-1} of VC) and (FB-17+ 0.38 ton ha^{-1} of VC), respectively. The increase in GY over the negative and positive controls was 38 and 24%, 27 and 12%, and 24 and 8% for the aforementioned treatments. Treatment FB-17 + 0.76 ton ha^{-1} of VC displayed statistically the first highest HY (4405 kg ha^{-1}). The second highest HY (3597 kg ha^{-1}) was scored by treatment FB-17 + 0.57 ton ha^{-1} VC. These above mentioned treatments showed HYs increments of 48 and 43%, and 36 and 30%, respectively.

The two-year statistical study revealed that, in comparison to the other treatments, the treatments at the SebetaHawase district (FB-17+ 0.76 ton ha^{-1} of VC) and (FB-17+ 0.57 ton ha^{-1} of VC) had comparatively the highest faba bean yields in all parameters. Based on biological yield as indicated by the above ranks, the aforementioned treatments are therefore the best options for faba bean growth in Pellicvertisol locations such as SebetaHawase, Ethiopia. The results of the current study at the district of SebetaHawase showed that faba bean AGBY, GY, and HY significantly increased with an increase in VC application; the greatest values were noted at 0.75 tons per hectare (Table 3).

This result is in line with studies by Anteneh and Abere (2017) and Özge (2021), who discovered that faba bean growth and grain output were greatly enhanced by the addition of VC and rhizobial inoculant. The study's results (Table 3) also reveal that, in contrast to the un-inoculated control, all inoculant- VC combined treatments demonstrated notably higher faba bean yield values. These findings corroborate those of Gopinath et al. (2011), Pashaki et al. (2016) and Özge (2021), who observed that the addition of biofertilizer and VC to bell pepper, french bean, and garden pea, and faba beans increased their fruit yield (t ha^{-1}) statistically when compared to the unaltered control. Increased concentrations of easily absorbed macro and micronutrients and soil microbiota, as well as derivatives of VC, are used to achieve this (Adhikary, 2012 and Lim et al., 2015).

Additionally, this study showed that at SebetaHawase, the mean AGBY (5150 kg ha^{-1}), GY (3757 kg ha^{-1}) and HY (4221 kg ha^{-1}) was statistically higher in the first year than in the second. This discrepancy might be explained by the fact that the first year's rainfall distribution was better than the second year's during the faba bean pod-setting stage. This conclusion is consistent with the findings of Anteneh and Abere (2017) and Asrat et al. (2023) who found that differences in annual rainfall cause differences in mean total biomass and grain production between seasons in faba beans.

3. Economic Analysis

The economic analysis results (Table 4) show that the combined application of (FB-17 + 0.76 ton of VC ha^{-1}) produced the maximum net benefit (ETB 135172 ha^{-1} approx. USD 341351244) at SebetaHawase. The total variable cost (TVC) is the total of all the expenses that a farmer may incur, such as labor, VC, rhizobial inoculant FB-17, field pricing of seed, etc. A sachet of rhizobial inoculant FB-17 (125 g) cost 40 ETB (approx. USD 101012) in the field. Eight sachets (1000 g ha^{-1}) of inoculant are the recommended national rate for faba bean seed dressing. In SebetaHwase district, the average field price for a kilogram of VC was 9 ETB (approx. USD 22727). The dominance study revealed that all treatments were none dominated, except treatment (0.76 ton ha^{-1} of VC) at SebetaHawase district. Thus, those non-dominated treatments are viable from an economic standpoint. The dominated treatment indicated above was excluded from further economic analysis because no beneficiary will choose an option that provides lower net benefits over one with higher net benefits and lower total variable costs.

The best marginal rate of returns 2848% and 1083% with treatment (FB-17), treatments (FB-17) and (FB-17+ 0.76 ton ha^{-1} VC), were obtained from faba bean production in SebetaHawase. Table (4) presents these finding.

Table (4). Economic analysis of the effect of rhizobial inoculant and vermicompost (VC) on faba bean grain yield (GY) at SebetaHawase district 2019-2021.

Treatment	**GY (kg ha^{-1})**	**AdjY (kg ha^{-1})**	**Gross benefit (Birr ha^{-1})**	**TVC (Birr ha^{-1})**	**Net benefit (Birr ha^{-1})**	**DO (Birr ha^{-1})**	**MC (Birr ha^{-1})**	**MNB (Birr ha^{-1})**	**MRR (%)**
Negative control	2084	1771	88570	0	88570				
FB-17	2306	1960	98005	320	97685	ND	320	9115	2848
Recommended N+	2531	2151	107567	1674	105893	ND	1354	8208	606
FB-17+ 0.38 ton ha^{-1} VC	2746	2334	116705	3740	112965	ND	2066	7071	342
FB-17+ 0.57 ton ha^{-1} VC	2873	2442	122102	5450	116652	ND	1710	3687	216
0.76 ton ha^{-1} VC	2308	1962	98090	6840	91250	D			
FB-17+ 0.76 ton ha^{-1} VC	3349	2847	142332	7160	135172	ND	1710	18520	1083

GY=grain yield, AdjY= adjusted yield by 15%, TVC= total variable cost, MC=marginal cost, MNB=marginal net benefit, MRR= marginal rate of return, DO= Dominance ND=none dominated= dominated VC= vermicompost.

Accordingly, for every ETB 1.0 (approx. USD 2525) invested in faba bean production utilizing treatments (FB-17 and (FB-17+ 0.76 ton ha^{-1} of VC) on SebetaHawasePellicvertisols, the producer can earn an additional return of ETB 28.5 (approx. USD 71971) and 11 (approx. USD 27778), respectively. Given that the experiment's minimum allowable rate of return was 100%, the aforementioned treatments were financially advantageous options in their respective districts.

CONCLUSION AND RECOMMENDATIONS

Field trials were carried out in SebetaHawase throughout the two main cropping seasons to investigate the combined impacts of VC and an elite rhizobial inoculant on the soil, as well as the agronomic and economic output of faba beans grown in pellicvertisol conditions. According to the findings, the treatments with the highest GYs were FB-17 + 0.76 ton ha^{-1} VC, FB-17 + 0.57 ton ha^{-1} VC, and FB-17 + 0.38 ton ha^{-1} VC. However, treatments FB-15 and FB-17 + 0.76 ton ha^{-1} VC at SebetaHawase turned out to be the most promising in terms of economic yields. These treatments are considered as highly promising candidates for further validation in farmers' fields at different agro-ecologies to identify them as best alternative bio-organic fertilizers for faba bean production on Pellicvertisol areas of Ethiopia, owing to their reasonable superiority in grain and economic yields. Except P, the analytical results of the soil were found to be sub-optimal for the production of faba beans.

This indicates that the production of faba beans on such pellicvertisol using the aforementioned treatments in conjunction with 46 kg P_2O_5 is reasonably promising in terms of biological and economic yields. Consequently, it is recommended that these treatments be verified under replicated conditions in a wider range of pellicvertisols and weather conditions of Ethiopia.

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