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Research Article

The Co-application Effects of Rhizobium Inoculant and Vermicompost on Faba Bean Yield: Insights from Sebeta Hawase District, Central Highlands of Ethiopia

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Abstract
In this study, the effects of co-applying vermicompost and an elite rhizobium inoculant on faba bean yields in agricultural settings in the Ethiopian region of Sebeta Hawase were examined. The farming seasons of 2019–20 and 2020–21 were used for the study. 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 terms of average TN (%), available P (ppm), and OC (%), treatments FB-17 + 0.76ton ha^{-1} of VC and FB-17 + 0.57ton ha^{-1} of VC demonstrated relative first and second superiority in the Sebeta Hawase district. At Sebeta Hawase, 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 were the treatments with the greatest mean GY (3349 kg ha^{-1}), (2873 kg ha^{-1}), and (2746 kg ha^{-1}).However, treatments FB-17 and FB-17 + 0.76 ton ha^{-1} VC at Sebeta Hawase had higher marginal rates of return, at 42848% and 1083%, respectively, according to the results of the partial budget study. These treatments are seen to be great candidates for further testing in farmers' fields across a variety of agro-ecologies in order to determine the best alternative organic fertilizers for faba bean production in Ethiopia's vertisol zones, such as Sebeta Hawase area.

Keywords: *Biological yield, FB-17, N-equivalence, Vermicompost.*

Introduction
Vicia faba L., or faba beans, are one of the most widely grown highland pulse crops in Ethiopia's colder highlands [8, 13]. Faba beans are mostly utilized as human food and as an animal feed source due to their high protein, mineral, vitamin, and fiber content [9]. Additionally, when faba beans coexist harmoniously with rhizobia, they bring significant amounts of reduce form of nitrogen to the soil environment [23]. Major faba bean-producing nations' average grain yields (3.7 t/ha) were 40% higher than Ethiopia's national average (2.2 t/ha) of the same crop [12, 20]. Research findings 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 beans growing 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 nitrogen and phosphorus insufficiency, which are inaccessible, unaffordable, have low use efficiency, and are environmentally unfriendly [6, 20]. 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.[20]

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 [3]. It is predicted that modulated legumes, such as pulses and oilseed legumes, fix nitrogen and add 21.45 Tg N to worldwide agricultural systems each year [3, 10]. Other alternative fertilizer technologies that have gained attention in sustainable agricultural production include organic fertilizer sources like vermicompost; 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 vermicompost integration, is available.

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

Materials and Methods

Field experimental sites

During the main cropping seasons of 2019/20 to 2020/21, the field experiment was carried out in the district of Sebeta Hawase. 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 [1]. Pellic vertisol, 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.

Elite rhizobial inoculant and vermicompost 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 vermicompost (which had a total nitrogen content of TN = 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.

Treatments and Experimental Design

Five treatments; (FB-17), (100% N from vermicompost; 0.76 ton ha^{-1}), (FB-17+50% N from vermicompost; 0.38 ton ha^{-1}), (FB-17+ 75% N from vermicompost; 0.57 ton ha^{-1}), and (FB-17+ 100% N from vermicompost; 0.76 ton ha^{-1}) were evaluated under the pellic vertisol condition of Sebeta Hawase district against 18 kg N ha^{-1} (positive control or standard) and no FB-17 and no vermicompost (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} Triple Superphosphate (TSP) 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 nitrogen 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.

Application of vermicompost 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 vermicompost in order to represent the (100%), (75%), and (50%) N contents of the vermicompost, respectively.

Each weighed bag containing the vermicompost was stuck down in a polyethylene plastic bag, and a representative percentage was written on it with a permanent marker. Integrated portions of the vermicompost in each treatment were added uniformly to each row of the plots before swinging the inoculated seeds.

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.

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 [26]. The total nitrogen content of the soil was determined by the wet-digestion procedure [16]. And available phosphorus was determined by the Bray-II extraction method.

Data collected and yield determination

Soil, agronomic, and economic data were collected and analyzed to determine the top-performing treatments in the Sebeta Hawase district of Ethiopia. The soil, agronomic and economic parameters were soil pH, available phosphorus, organic carbon, total nitrogen, above-ground biomass yield (AGBY), grain yield (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 SAS statistical platform version 9.3 [24].

Means were compared with the Least Significance Difference (LSD) at a 5% probability level [24]. 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 [7].

Results and Discussion

Soil test result

The soil's chemical properties were found similar among the experimental sites in Sebeta Hawase 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 [25]. The mean of organic carbon, available phosphorus and total nitrogen contents of the trial sites were 1.21%, 9.8 ppm and 0.08% respectively. The mean organic carbon, available phosphorus and total nitrogen contents of the trial locations were found in low ratings [25].

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

Parameter	Sebeta Hawase (average)	Range	Test Method
pH	7.5	7.4-8.5	1:2.5 H2O
Total N (%)	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) [26]

Tables 2 showed the combined effects of an elite rhizobium inoculant and vermicompost on pH, total N (%), available P (ppm), and OC (%) following planting. The accompanying table demonstrates that the rhizobium-vermicompost 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 vermicompost in the presence of rhizobia may be the reason of this. This result is in line with studies by, [11, 19, and 5].

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

Treatment	Sebeta Hawase (average)			
	pH	Total N (%)	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 the both district, 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 vermicompost 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 [15].

Table 2 above shown 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 [18,5]. In comparison to the negative control at Sebeta Hawase district, the aforementioned treatments shown increases in N(%), available P(ppm), and OC(%) of (94%, 27% and 32%) and (40%, 23% and 32%), respectively.

Inoculation and vermicompost response to faba bean yields at Sebeta Hawase districts in 2019-2021

The collective analysis of the two years of data at Sebeta Hawase 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% and 22% and 45% and 18% above the negative and positive controls, respectively, were seen in the aforementioned treatments.

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 tired 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. GY increases over the negative and positive controls were seen to be (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 (3597kg 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.

Table 3: Yield response of faba bean to the combined effect of rhizobial inoculant and vermicompost at Sebeta Hawase 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			
Sebeta Hawase (2019/20)	4097b	1442b	1978b
Sebeta Hawase (2020/21)	5150a	3757a	4421a
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= Haulms yield, VC= vermicompost.

The two-year statistical study revealed that, in comparison to the other treatments, the treatments at the Sebeta Hawase 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 Pellic vertisol locations such as Sebeta Hawase, Ethiopia. The results of the current study at the district of Sebeta Hawase showed that faba bean AGBY, GY, and HY significantly increased with an increase in vermicompost application; the greatest values were noted at 0.75 tons per hectare (Tables 3).

This result is in line with studies by, [4, 21] which discovered that faba bean growth and grain output were greatly enhanced by the addition of vermicompost and rhizobial inoculant. The study's results (Tables 3) also revealed that, in contrast to the un-inoculated control, all inoculant-vermicompost combined treatments demonstrated notably higher faba bean yield values. These findings corroborate those of, [14, 22, 21] who observed that the addition of biofertilizer and vermicompost 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 vermicompost, are used to achieve this [2, 17].

Additionally, this study showed that at Sebeta Hawase, the mean AGBY (5150 kg ha^{-1}), GY (3757 kg ha^{-1}) and HY (4221 kg ha^{-1}) statistically higher in the second year than in the first. This discrepancy might be explained by the fact that the second year's rainfall distribution was better than the first year's during the faba bean pod-setting stage. This conclusion is consistent with the findings of, [4, 5] who found that differences in annual rainfall cause differences in mean total biomass and grain production between seasons in faba beans.

Economic analysis

The economic analysis results (Tables 4) showed that the combined application of (FB-17 + 0.76 ton of VC ha^{-1}) produced the maximum net benefit (ETB 135172 ha^{-1}) at Sebeta Hawase. The total variable cost (TVC) is the total of all the expenses that a farmer may incur, such as labor, vermicompost, rhizobial inoculant FB-17, field pricing of seed, etc. A sachet of rhizobial inoculant FB-17 (125g) cost 40 ETB in the field. Eight sachets (1000 g ha^{-1}) of inoculant are the recommended national rate for faba bean seed dressing.

In Sebeta Hwase district, the average field price for a kilogram of vermicompost was 9 ETB. The dominance study revealed that all treatments were none dominated, except treatment (0.76 ton ha^{-1} of VC) at Sebeta Hawase 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 Sebeta Hawase. Tables 4 present these finding.

Table 4 Economic analysis response of rhizobial inoculant and vermicompost faba bean GY at Sebeta Hawase 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 1.00 invested in faba bean production utilizing treatments (FB-17 and (FB-17+ 0.76 ton ha^{-1} of VC) on Sebeta Hawase Pellic vertisols, the producer can earn an additional return of ETB 28.5 and 11. 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 Sebeta Hawase throughout the two main cropping seasons to investigate the combined impacts of vermicompost and an elite rhizobial inoculant on the soil, as well as the agronomic and economic output of faba beans grown in pellic vertisol conditions. According to the findings, the treatments with the highest grain yields 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 Sebeta Hawase 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 Pellic vertisol areas of Ethiopia, owing to their reasonable superiority in grain and economic yields. Except phosphorus, 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 pellic vertisol 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 pellic vertisols and weather conditions of Ethiopia.

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Conflict of Interest

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