

Research Article

The Effects of Organic Fertilizers on Soil, Biology, and Economic Outputs of Faba Beans (*Vicia faba* L.) in Kersa Malima District, Central Highlands of Ethiopia

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Abstract

This study aimed to analyze the soil, biological and economic responses of faba bean to the combined effects of organic fertilizers in farm settings located in the Ethiopian district of Kersa Malima in 2019/20 and 2020/21 cropping seasons. The treatments were laid out in a randomized complete block design with three replications. The collected data were subjected to analysis of variance by SAS statistical platform version 9.3. Means were compared with the Least Significance Difference (LSD) at a 5% probability level. To compute the economic advantage of the intervention, farm gate prices of inputs and outputs were considered and marginal rate of return (% MRR) was worked out for each treatment, and values ≥ 100 was set as profitable in absolute terms. The average outcome of the two years' worth of data analysis showed that there was substantial ($p \leq 0.05$) difference in all parameters among the treatments in the district. Treatments (FB-17 + 0.76 ton ha⁻¹ of vermicompos) and (FB-17 + 0.57 ton ha⁻¹ of vermicompos) demonstrated relative first and second superiority in average TN (%), available P (ppm) and OC (%) at the district. Treatments (FB-17 + 0.76 ton ha⁻¹ of vermicompost), (FB-17 + 0.57 ton ha⁻¹ of vermicompost), and (FB-17 + 0.38 ton ha⁻¹ of vermicompost) yielded the highest mean grain yields (3588 kg ha⁻¹), (3316 kg ha⁻¹), and (3216 kg ha⁻¹) in the district of Kersa Malima. However, treatment FB-17 at this district had higher marginal rates of return 5624% according to the results of the partial budget analysis. To find the finest organic fertilizer substitutes for faba bean production in Ethiopia's Vertisol zones, such as the Kersa Malima district, these treatments are considered to be excellent candidates for additional testing in farmers' fields across a variety of agro-ecologies.

Keywords

Grain Yield, Aboveground Biomass Yield, Haulm Yield, Rhizobium, Vermicompost

1. Introduction

The cooler highlands of Ethiopia are home to faba beans (*Vicia faba* L.), one of the most extensively produced highland pulse crops [1, 2]. Because of their high protein, mineral, vitamin, and fiber contents, faba beans are primarily used as food for people and as a feed source for animals [1]. When

faba beans are symbiotically associated with rhizobia, they also contribute a significant amount of reduced nitrogen to the soil environment [3, 4]. 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 [5]. [3,

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Received: 30 August 2024; **Accepted:** 19 September 2024; **Published:** 11 February 2025



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[6], 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 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, 7]. 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 [6, 8].

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 inoculants [9]. It is predicted that nodulated legumes, such as pulses and oilseed legumes, fix nitrogen and add 21.45 Tg N to worldwide agricultural systems each year [9, 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 low C: N ratio, high porosity, aeration, drainage, water holding capacity, microbial activity, and 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 inoculants 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. Therefore, the goal of this activity is to examine how soil conditioning potential and faba bean grain and economic yields in Ethiopia's central highlands, specifically in Kersa Malima district, are enhanced by the combination of organic fertilizers like elite rhizobium inoculant and vermicompost.

2. Materials and Methods

2.1. Field Experimental Sites

During the main cropping seasons of 2019/20 to 2020/21, the field experiment was carried out in the district of Kersa Malima. For the previous five years, these experimental sites had no history of rhizobial inoculation. Kersa Malima is situated between 1500 and 2900 meters above sea level, with latitude of 8° 29' 59.99" N and a longitude of 38° 34' 59.99"

E. According to [11], Kersa Malima is characterized by an average temperature between 10 and 19 °C and an average rainfall between 974 and 1319 mm. Pellic Vertisol, which has slightly acidic to mildly alkaline properties, predominated in the testing sites in this district. In the experimental location, faba beans, tef, and wheat are the most often produced crops.

2.2. Elite Rhizobial Inoculant and Vermicompost Source

The Holeta Agricultural Research Center's Biological and Organic Soil Fertility Management Research Program provided an elite faba bean rhizobial inoculant (FB-1017) 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.

2.3. 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 pellic vertisol conditions of Kersa Malima 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 1m, 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 of triple superphosphate (TSP) at the time of planting. The positive control received 18 kg nitrogen per hectare 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.

2.4. Application of Vermicompost to the Soil

Well-prepared vermicompost was weighed in N equivalent base (0.76 ton ha⁻¹), (0.57 ton ha⁻¹), and (0.38 ton ha⁻¹) to represent (100%), (75%), and (50%) N contain of the vermicompost, in that order. Each weighed 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 on each row of the plots

prior swing the inoculated seeds.

2.5. 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; 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, 8].

2.6. Soil Sample Analysis

A combination of soil samples were composed from random spots of the trial plots at a depth of 0-30 cm just during trial field arrangement. The soil samples were air-dried and ground to pass through a 2 mm sieve. Soil pH was measured in 1:2.5 soils to water ratio. The wet digestion method was used to determine soil organic carbon [12]. Total nitrogen content of the soil was determined by the wet-digestion procedure [13]. And available phosphorus was determined by the Bray-II extraction method [12].

2.7. Data Collected and Yield Determination

Soil, agronomic and economic data were collected and analyzed to determine the top-performing treatments in the

Kersa Malima 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 SAS statistical platform version 9.3 [14]. Means were compared with the Least Significance Difference (LSD) at a 5% probability level. To compute the economic advantage of the intervention, farm gate prices of inputs and outputs were considered and marginal rate of return (% MRR) was worked out for each treatment, and values ≥ 100 was set as profitable in absolute terms [15].

3. Results and Discussion

3.1. Soil Test Result

The soil's chemical properties were found similar among the experimental sites at Kersa Malima district (Table 1). The soil mean pH of the trial locations was 7.9. Therefore, trial sites were grouped in the ratings of moderately alkaline conditions [12]. The mean of organic carbon, available phosphorus and total nitrogen contents of the trial sites were 1.14%, 9.6 ppm and 0.07 respectively. The mean organic carbon, available phosphorus and total nitrogen contents of the trial locations were found in low ratings [12].

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

Parameter	Kersa Malima (average)	Range	Test Method
pH	7.9	7.4-8.5	1:2.5 H ₂ O
Total N (%)	0.07	0.06-0.09	Modified Kjeldhal
Available P (ppm)	9.6	7.9-11.6	Bray II
OC (%)	1.14	1.13-1.29	Walkley and Black [28]

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	Kersa Malima (average)			
	pH	Total N (%)	Available P (ppm)	OC (%)
No inoculation	8.1	0.073	9.46	1.1
Recommended N	8.0	0.073	10.8	1.02
FB-17	7.9	0.076	10.65	1.0
0.76 ton ha ⁻¹ VC	7.9	0.077	10.84	1.06

Treatment	Kersa Malima (average)			
	pH	Total N (%)	Available P (ppm)	OC (%)
FB-17 + 0.38 ton ha ⁻¹ VC	7.96	0.074	11.72	1.08
FB-17 + 0.57 ton ha ⁻¹ VC	7.88	0.077	11.76	1.12
FB-17 + 0.76 ton ha ⁻¹ VC	7.99	0.077	11.85	1.13

Table 2 showed the combined effects of an elite rhizobium inoculant and vermicompost on pH, total nitrogen; TN (%), available phosphorus; P (ppm), and organic carbon; OC (%) following planting. The accompanying table clearly demonstrates that the rhizobium-vermicompost treatments relatively decreased the average soil pH in Kersa Malima 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 [17, 18, 19].

In the 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 macro-nutrients, growth promoters, enzymes, hormones, and other elements [20]. Table 2 above shown that in the district treatments (FB-17 + 0.76 ton ha⁻¹ of vermicompost) and (FB-17 + 0.57 ton ha⁻¹ of vermicompost) demonstrated relative first and second superiority in total nitrogen; TN (%), available phosphorus; P (ppm) and organic carbon; OC (%). These outcomes were consistent with the findings of [17, 21]. In comparison to the negative control at Kersa Malima district, the aforementioned treatments shown increases in total nitrogen; TN (%), available phosphorus; P (ppm), and organic carbon; OC (%) of (90%, 20% and 3%) and (90%, 20% and 2%).

3.2. Inoculation and Vermicompost Response to Faba Bean Yields at Kersa Malima District in 2019-2021

All metrics showed substantial ($p < 0.05$) variance among the treatments, according to the combined analysis of the two years' worth of data (Table 3). Years had a statistically significant impact on every indicator ($p < 0.05$). Treatment (FB-17

+ 0.76 ton ha⁻¹ of vermicompost) had the highest above-ground biomass yield score (2950kg ha⁻¹) despite the fact that no statistically significant differences were found among the treatments, with the exception of treatments FB-17 and the negative control which exhibited statistically the least above-ground biomass yield (2545 kg ha⁻¹) and (2400kg ha⁻¹), in that order. FB-17 + 0.76 ton ha⁻¹ of vermicompost showed above-ground biomass yield increment of 19% and 11% over the negative and the positive controls, respectively.

There were no statistically significant variations in grain yield among treatments (FB-17+ 0.76 ton ha⁻¹ of vermicompost), (FB-17+ 0.57 ton ha⁻¹ of vermicompost) and (FB-17+ 0.38 ton ha⁻¹ of vermicompost). However, as compared to treatments that showed statistically the least grain yield, treatment (FB-17 + 0.76 ton ha⁻¹ of vermicompost), (FB-17 + 0.57 ton ha⁻¹ of vermicompost) and (FB-17+ 0.38 ton ha⁻¹ of vermicompost) demonstrated the highest grain yield (3588 kg ha⁻¹), (3316 kg ha⁻¹) and (3216 kg ha⁻¹), in a statistically meaningful way, respectively. The above treatments showed grain yield increment of (47% and 29%), (42% and 23%) and (41% and 20%) over the negative and positive controls, respectively. Among the other treatments, treatment (FB-17+ 0.76 ton ha⁻¹ of vermicompost) demonstrated the largest Haulms (4357 kg ha⁻¹) statistically. The treatments with the second-highest Haulms yields (3523 kg ha⁻¹) and third-highest Haulms yields (3498 kg ha⁻¹) were FB-17 + 0.57 ton ha⁻¹ of vermicompost and FB-17 + 0.38 ton ha⁻¹ of vermicompost. Haulms yield increments of 41% and 23% were seen in treatment FB-17 + 0.57 ton ha⁻¹ of vermicompost compared to the negative and positive controls.

According to the two-year statistical analysis, treatments (FB-17+ 0.76 ton ha⁻¹ of vermicompost), (FB-17+ 0.57 ton ha⁻¹ of vermicompost) and (FB-17+ 0.38 ton ha⁻¹ of vermicompost) showed relatively the greatest faba bean yields in all parameters at the Kersa Malima district when compared to the other treatments. Consequently, the above-mentioned treatments are the best candidates for faba bean growing Pellic Vertisol areas like Kersa Malima of Ethiopia in terms of biological yield as recorded in ranks above.

Table 3. Yield response of faba bean to the combined effect of rhizobial inoculant and vermicompost at Kersa Malima district in 2019-2021 growing seasons.

Treatment	AGBY (kg ha ⁻¹)	GY (kg ha ⁻¹)	HY (kg ha ⁻¹)
Negative control	2400cb	1906c	2553d
Recommended N+	2623abc	2558b	3329bc
FB-17	2545bc	2640b	3376bc
0.76 ton ha ⁻¹ VC	2742abc	2596b	2731cd
FB-17 + 0.38 ton ha ⁻¹ VC	2754ab	3216a	3498b
FB-17 + 0.57 ton ha ⁻¹ VC	2887ab	3316a	3523b
FB-17 + 0.76 ton ha ⁻¹ VC	2950a	3588a	4357a
LSD (P<0.05)	384	495	661
Year			
Kersa Malima (2019/20)	543b	3278a	3534a
Kersa Malima (2020/21)	5179a	2384b	3143b
LSD (P<0.05)	205	265	353
CV (%)	11	15	17
Mean	2861	2831	3338

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

The results of the current study at the district of Kersa Malima showed that faba bean above-ground biomass yield, grain yield and haulms yield significantly increased with an increase in vermicompost application; the greatest values were noted at 0.75 tons per hectare (Table 4). This result is in line with studies by [3, 22, 23], which discovered that faba bean growth and grain output were greatly enhanced by the addition of vermicompost and rhizobial inoculant.

The study's results (Table 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 [3, 23, 24 25], 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 [26, 27, 3, 28].

Additionally, this study showed that at Kersa Malima, the mean grain yield (3278 kg ha⁻¹) was statistically greater, and the mean haulms yield (3534 kg ha⁻¹) was numerically better in the first year. 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 [3,

17, 22], who found that differences in annual rainfall cause differences in mean total biomass and grain production between seasons in faba beans.

3.3. Cost-benefit Analysis

The partial budget analysis results (Table 4) showed that the combined application of (FB-17 + 0.76 ton of vermicompost ha⁻¹) produced the maximum net benefits (ETB 215,412ha⁻¹) at Kersa Malima. 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 the Kersa Malima district, the average field price for a kilogram of vermicompost was 9 ETB. The dominance study revealed that all treatments were none dominated, with the exception of treatment (0.76 ton ha⁻¹ of vermicompost) at Kersa Malima 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.

Table 4. Partial budget analysis response of elite rhizobial inoculant and vermicompost to faba bean GY at Kersa Malima 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	1906	1620	81005	0	161712				
FB-17	2640	2244	112200	320	179710	ND	320	17998	5624
Recommended N+	2558	2174	108715	1674	195526	ND	1354	15816	1169
FB-17+ 0.38 ton ha ⁻¹ VC	3216	2734	136680	3740	200770	ND	2066	5244	254
FB-17+ 0.57 ton ha ⁻¹ VC	3316	2819	140930	5450	203310	ND	1710	2540	149
0.76 ton ha ⁻¹ VC	2596	2207	110330	6840	156445	D			
FB-17+ 0.76 ton ha ⁻¹ VC	3588	3050	152490	7160	215412	ND	1710	12102	708

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

The best marginal rate of returns 5624% with treatment FB-17 was obtained from faba bean production in Kersa Malima Table 4 present these findings. Accordingly, for every ETB 1.00 invested in faba bean production utilizing treatment FB-17 on Kersa Malim's Vertisols, the producer can earn an additional return of ETB 56, Given that the experiment's minimum allowable rate of return was 100%, the aforementioned treatment was financially advantageous options at Kersa Malima district.

4. Conclusion and Recommendations

Field trials were carried out in Kersa Malima over the course of the two main cropping seasons in order to investigate the combined impacts of vermicompost and an elite rhizobial inoculant on the soil, as well as the biological and economic output of faba beans grown in 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, treatment FB-17 at Kersa Malima turned out to be the most promising in terms of economic yield. Due to their reasonable superiority in grain and economic yields, these treatments are regarded as highly promising candidates for further validation in farmers' fields at various agro-ecologies to identify them as the most effective alternative bio-organic fertilizers for faba bean production in Vertisol areas of Ethiopia, such as Kersa Malima.

With the exception of 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 vertisol using the aforementioned treatments in conjunction with 46 kg P₂O₅ is reasonably promising in terms of biological and economic yields. Therefore, it is advised that these treatments with the highest grain and economic har-

vests be verified under replicated conditions in a broader range of Vertisols and weather conditions in Ethiopia.

Abbreviations

AGBY	Above Ground Biomass Yield
GY	Grain Yield
HY	Haulm Yield
LSD	Least Significance Difference
MNB	Marginal Net Benefit
MRR	Marginal Rate of Return
RCBD	Randomized Complete Block Design

Author Contributions

Mulugeta Mekonnen: Conceptualization, Data collection, Data Analysis, Investigation, Methodology, Project administration, Supervision, Writing– original draft, Writing – review & editing

Gezahegn Tamiru: Data collection, Formal Analysis, review and editing

Acknowledgments

Sincere gratitude is extended by the authors to the Ethiopian Institute of Agricultural Research (EIAR) for providing financing for this project. The authors would also like to express their gratitude to all of the field and technical assistants of the Holeta Agricultural Research Center's Biological and Organic soil fertility management program for their outstanding assistance in overseeing the experimental fields, collecting data, and managing the microbiological laboratory tasks.

Funding

The author(s) did not get any funding for the publishing of this research, despite the Ethiopian Institute of Agricultural Research supporting this activity.

Conflicts of Interest

The authors declare no conflicts of interest.

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