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Effect of tillage and biofertilizers inoculations on physiological growth indices, productivity and profitability of faba bean (*Vicia faba* L.)

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ABSTRACT

A field study was conducted at the research farm of MAP section, Genetics and Plant Breeding (G&PB), CCSHAU, Hisar during Rabi 2019-20 to evaluate the growth, productivity and economic viability of faba bean under different tillage practices and biofertilizer inoculations. The experiment followed a factorial randomized block design (FRBD) with 3 replications comprising of two types of tillage practices: Zero Tillage (ZT) and Conventional Tillage (CT), along with 8 different combinations of biofertilizer inoculation consisting of Rhizobium spp., Vesicular Arbuscular Mycorrhizae (VAM) and Phosphorus Solubilizing Bacteria (PSB). Conducting the study posed challenges such as managing variability in soil properties under different tillage systems and ensuring uniform establishment of biofertilizer inoculants in the field conditions. The results showed that seed yield (kg/ha) and straw yield (kg/ha) under ZT(3286, 4839) were significantly higher than CT (2672, 3931), respectively by 23% approximately. Similarly, all the yield attributes viz., seeds per pod, pods/plant and pod length (cm), except 100-seed weight, were significantly improved under ZT over CT. The highest value for yield and yield attributes was recorded with the seed inoculation treatment of Rhizobium spp. + PSB + VAM and was at par with Rhizobium spp. + VAM. The cost of cultivation using the zero-tillage method was lower (₹26,185/ha) than the conventional tillage (₹32,795/ha), resulting in a cost reduction of ₹6,610/ha. Additionally, the ZT generated higher net returns (₹39,542/ha), gross returns (₹65,728/ha) and benefit-cost ratio (2.51) compared to CT (₹20,652/ha, ₹53,448/ha and 1.63, respectively), representing an increase of ₹12,280/ha, ₹18,890/ha, and 0.88, respectively. The Rhizobium spp. + PSB + VAM combination produced the highest net returns (₹38,643/ha), gross returns (₹68,433/ha), and benefit-cost ratio (2.35), which were higher than the control by ₹15,877/ha, ₹16,476/ha, and 0.53, respectively. Overall, this study contributes valuable evidence on the superiority of zero tillage in enhancing the productivity and profitability of faba bean, while also highlighting the synergistic effect of multiple biofertilizer inoculations. These findings can guide sustainable crop management practices, reduce cultivation costs, and promote resource-efficient agriculture in pulse-based cropping systems.

Keywords: *Faba bean, Phosphate Solubilizing Bacteria, Rhizobium, Tillage, VAM, Zero-tillage, Profitability, Sustainable Agriculture.*

Introduction

Tillage is one of the most significant inputs that influence soil health, crop growth and yield. While the optimum tillage can overcome the edaphic constraints, the long-term conventional tillage may result in various unenviable consequences such as accelerated soil erosion, the disintegration of the soil structure, loss of organic carbon and plant nutrient [1]. Intensive tillage and crop establishment activities results in approximately one-fourth of total production costs, resulting in lower net returns[2]. [3]evaluated the performance of faba bean, chickpea & pea under CT and no-tillage systems and found that no. of pods per m^2 and seed yield were statistically higher under ZT in over CT. [4]reported that seed, straw yield and various chickpea yield attributes like branches/plant, pods/plant and seeds/pod were significantly higher in ZT than other tillage systems (*i.e.,* single, two, three and four tillage), whereas no significant effect of tillage was observed on 100-seed weight. In order to take care of the food requirements of the ever-increasing world population, chemical fertilizers are applied on a large scale to enhance crop yield. However, the reckless use of these agrochemicals has resulted in pollution and put public health in jeopardy. In addition, soil's nutrient balance and biological health are deteriorating, as are the soil's physical properties and quality. Seed treatment with biofertilizers inoculations in crop production is a valuable, low-cost input. However, so far, there is a wide gap in research on studying the combined inoculation effect of various bioinoculants on the growth and yield of faba bean. A study conducted by [5] in faba bean revealed that dual inoculation of PSB and *Rhizobium spp.* gave significantly higher seed yield over control as well as single inoculation, which shows the existence of synergistic interaction when two types of microorganisms were combined. Keeping the above in view, this research paper aims to examine the effect of different tillage methods and the application of biofertilizers on the physiological growth indices, yield and profitability of faba bean.

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MATERIALS AND METHODS

The field study was conducted at MAP Section Research farm (29°10' N latitude, 75°46' E longitude coordinates), Department of G&PB of CCSHAU, Hisar, India, during *Rabi* 2019-20. The experimental field consisted of sandy loam soil having $pH_{(1:2)}$ 7.90 and electrical conductivity ($EC_{1:2}$) 0.26 dS/m, available nitrogen (low), available phosphorus (Medium) and available potassium (High). The weekly weather data documented by Agro-Meteorology Observatory CCS HAU, Hisar, during the crop growing season 2019-20 is depicted in figure1. It can be seen from the Figure 1 that the mean weekly maximum temperature ranged from 2.6 to 22.3^{o} C and the minimum temperature ranged from 11.9 to 37.5^{o} C, respectively, during the crop cycle. The morning and evening RH (%) ranged from 70 to 100 and 24 to 82, respectively. While the sunshine hours ranged from 1.1 to 9.9 during *Rabi* 2019-20. During the crop season, there was a total of 138.3 mm of precipitation and 53.8 mm of pan evaporation (PE).

Experimental layout: The experiment was conducted using a factorial randomized block design (FRBD) with three replications. The experiment consisted of 16 treatment combinations comprising 2 methods of tillage : Zero Tillage (ZT), Conventional Tillage (CT) and 8 different biofertilizer combinations: Control (No Inoculation), PSB, *Rhizobium spp.*, VAM, *Rhizobium spp.* + VAM, *Rhizobium spp.* + PSB, PSB + VAM and *Rhizobium spp.* + PSB + VAM. Tillage operations were carried out with a tractor-drawn disc harrow and cultivator to prepare seed bed followed by planking in CT blocks. While no tillage operation was carried out in ZT blocks. Seed treatment was done using jaggery as adhesive. Each plot was 5.4 m by 5 m (27 m^2) in gross. The crop was sown on 6th December 2019. Seed was used @100 kg/ha of HFB-1 variety of faba bean for sowing of crop. The recommended nitrogen, phosphorus dose of 40 kg nitrogen per hectare and 60 kg P_2O_5/ha was applied in all the plots except control. The complete dose of nitrogen and phosphorus fertilizer was applied at the time of sowing.

Growth indices and yield analysis: The plant population per m.r.l. (meter row length) was counted at 30 DAS and harvest. Days to 50% flowering were recorded for individual plots separately when 50% of the plants of the plot-initiated flowering. The height of five plants randomly picked from every plot was recorded periodically at 60, 90, 120 DAS and at harvest.

five randomly chosen plants were taken from each plot to count the number of branches per plant at 60, 90 and 120 DAS and the mean was calculated. Dry matter accumulation was also recorded at all the above-mentioned stages.

The number of pods per plant was counted at the time of harvest from five randomly chosen plants, and the average number of pods per plant was calculated. The length of ten randomly picked pods per plot was measured at the time of harvesting and the mean was calculated. Ten pods per plot were harvested, manually threshed, and the total number of seeds was counted. The mean was computed to express the number of seeds/pod. At the time of threshing, a 100-seeds sample were taken from a random sample from every plot and weighed to obtain the seed index. The plants from 1m^2 of each plot were harvested, dried and threshed manually separately. The weight of seeds per m^2 was recorded and converted into kg/ha. Each plot's 1 m^2 of total above-ground biomass was collected separately, weighed, and converted to kg/ha.

Straw yield = biological yield - seed yield.

$$\text{Harvest Index, HI (\%)} = \frac{\text{Seed yield}}{\text{Biological yield}} \times 100$$

Growth indices: 1) Absolute growth rate = $\frac{D_2 - D_1}{t_2 - t_1}$

Where, D_1 and D_2 are dry weights of plants at times t_1 and t_2, respectively

2) Crop growth rate = $\frac{1}{P}\frac{D_2 - D_1}{t_2 - t_1}$

Where, D_1 and D_2 are dry weights of plants at times t_1 and t_2, respectively and P is land area.

3) Relative growth rate = $\frac{\log e D_2 - \log e D_1}{t_2 - t_1}$

Where, D_1 and D_2 are dry weights of plants at times t_1 and t_2, respectively

Economics: Gross returns realized from different treatments of investigation was computed by considering prevailing market prices during the study period.

Net Returns = Gross Returns – Cost of cultivation of treatment

$$\text{Benefit-cost ratio(B:C)} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

Statistical analysis: To conduct statistical analysis and interpret the findings the methodology outlined by Panse and Sukhatme (1985) was utilized[6]. To assess and compare the effectiveness of various treatment Fisher's (1950) analysis of variance technique (ANOVA) was used[7]. The treatments were compared using the critical difference (C.D.) to ascertain their significance, and significance tests were carried out at the 5% level of significance.

$$CD = \sqrt{\frac{2xEMS}{n}} \times t\ value\ at\ 5\%$$

Where,

CD = Critical difference

EMS = Error mean square

t = value of t-distribution at 5% level of error degree of freedom

n = number of observations of that factor for which C.D. is to be calculated at 5%

RESULTS AND DISCUSSION

*Plant population and phenology:*The results on phenological observation depicted in table 1 indicated that tillage had a non-significant effect on days to 50% flowering, however, ZT took a numerically larger number of days to 50% flowering. ZT also took significantly more days to physiological maturity than CT. The reason might be improved earlier seed emergence in loose soil structure imparted in CT as compared to ZT resulting in better seed soil contact, thus inducing early days to 50% flowering and physiological maturity. The plant population was significantly lower under ZT in comparison to CT at 30 DAS (table 1) whereas it was recorded as non-significant at harvest. It is in confirmation with the findings of [8] and [9] whereas it was recorded as non-significant at harvest This might be due to early and better emergence of faba bean seeds owing to proper seed soil contact in conventional tillage. No significant effect of biofertilizer inoculations was observed on plant population at both 30 DAS and harvest, 50% flowering and physiological maturity.

Growth: There was no significant difference observed in plant height due to tillage method at 60 DAS but it was significantly higher in ZT over CT at 90 DAS, 120 DAS and harvest (table 1) which might be indicated as resulting from optimum moisture conditions in soil for uptake of available nutrients by plants[4]. The plant height was significantly influenced by different biofertilizer inoculations at all the observed growth stages *viz.,* 60, 90, 120 DAS and harvest (table 1).

Maximum plant height was recorded in *Rhizobium spp.* + PSB + VAM at all the observed growth stages. Phosphate-solubilizing microorganisms mineralize organic P by producing phosphatases like phytase. The number of branches per plant were also found significantly higher in ZT over CT at all the recorded stages except 60 DAS (table 1). *Rhizobium spp.* + PSB + VAM produced a higher number of branches per plant by 12.7%, 19.2%, 27.9% and 28.5% over control at all the observation stages.

Growth indices: The data related to various growth indices like Crop growth rate, Absolute growth rate (AGR) and Relative growth rate (RGR) is given in table 3. The close perusal of data showed that the absolute growth rate was significantly affected by tillage as well as biofertilizer treatments at all the stages except 0-60 DAS interval. Zero tillage recorded higher absolute growth rate (g/day) values of 0.65, 1.50 and 3.48 as compared to CT (0.64, 1.43 and 3.27) at the respective stage. Among different biofertilizer treatments *Rhizobium spp.* + PSB + VAM, closely followed by *Rhizobium spp.* + VAM gave higher absolute growth rate values of 0.66, 1.65 and 3.94, respectively at 0-60 DAS, 61-90 DAS and 91 DAS–harvest stage. The crop growth rate was significantly higher by 5.0% and 6.1% under zero tillage over conventional tillage at 61-90 DAS and 91 DAS harvest stages, respectively. Among the biofertilizer treatments, maximum crop growth rate at 61-90 DAS stage was observed in *Rhizobium spp.* + PSB + VAM (3.66) followed by *Rhizobium spp.* + VAM (3.48), PSB + VAM (3.38), *Rhizobium spp*. + PSB (3.29), *Rhizobium spp.* (3.24), VAM (3.19), PSB (2.94) and control (2.92). While, at 91 DAS–harvest stage, maximum crop growth rate was recorded in *Rhizobium spp.* + PSB + VAM (8.76), which was significantly higher by 2.31 g/m^2/day over control (6.45). The relative growth rate (mg/g/day) was higher under zero tillage over conventional tillage by 0.63, 1.19 and 1, respectively at 0-60 DAS, 61-90 DAS and 91 DAS-harvest.

The highest value of relative growth rate (mg/g/day) was recorded in *Rhizobium spp.* + PSB + VAM i.e., 61.31, 149.63 and 104.03 at 0-60 DAS, 61-90 DAS and 91 DAS–harvest, respectively which were 0.91, 4.89 and 4.69 mg/g/day higher than control at respective stages.

Yield attributes and yield: In the present study, all the yield attributes *viz.,* seeds/pod, pods/plant and pod length (cm) except 100-seed weight were significantly improved under ZT in comparison to CT (table 2). The seed yield under zero tillage (3286 kg/ha) was significantly higher by 23% than conventional tillage (2672 kg/ha), which is in contradiction to [10] which reported more yield of soyabean in ZT as compared to CT. Similarly, straw yield was significantly greater in ZT as compared to CT. Improved physico-chemical soil characteristics and soil organic matter may be connected to higher seed yield and biomass output in the zero-tillage method[11]. Zero tillage yielded more pods per plant, which is associated with increased branching[4]. Plant growth and development may be aided by more favourable microclimatic conditions of zero tillage plots.

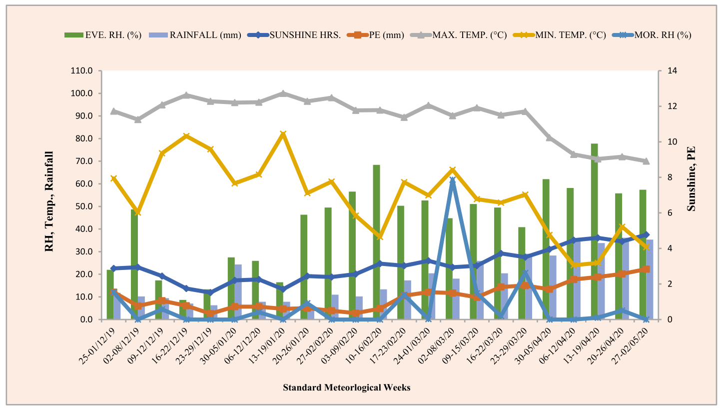

Figure 1. Weekly weather data during Rabi 2019-20

Table 1: Effect of tillage and biofertilizers on the phenology, number of branches per plant and periodic plant height (cm) of faba bean

Treatments	Days to 50 percent flowering	Days to physiological maturity	Plant Population (no. per meter row length)		Branches per plant (no.)				Plant height (cm)			
			30DAS	At harvest	60 DAS	90 DAS	120 DAS	At Harvest	60 DAS	90 DAS	120 DAS	At harvest
Tillage method												
T_1: Conventional Tillage	67.5	135.3	10.08	8.30	2.35	3.03	3.13	3.15	43.36	88.55	107.97	109.00
T_2: Zero Tillage	70.0	140.3	9.73	8.12	2.37	3.12	3.29	3.31	44.16	91.18	110.16	111.79
SEm ±	0.8	1.2	0.10	0.09	0.02	0.03	0.04	0.04	0.29	0.65	0.74	0.68
CD at 5%	NS	3.7*	0.29*	NS	NS	0.08*	0.11*	0.12*	NS	1.88*	2.16*	1.99*
Biofertilizers inoculations												
B_1: Control (No inoculation)	67.1	136.4	9.53	7.98	2.20	2.81	2.83	2.84	42.35	85.83	102.58	104.23
B_2: *Rhizobium spp.*	68.9	137.4	10.01	8.28	2.38	3.06	3.14	3.16	43.00	89.95	109.17	109.82
B_3: PSB	68.2	136.8	9.70	8.09	2.24	2.84	2.86	2.87	43.64	86.57	103.87	104.93
B_4: VAM	68.4	137.1	9.86	8.18	2.36	3.01	3.10	3.13	42.75	89.52	108.22	109.40
B_5: *Rhizobium spp.* + PSB	69.2	137.6	9.94	8.22	2.40	3.10	3.31	3.32	44.25	90.20	109.72	110.07
B_6: *Rhizobium spp.* + VAM	69.2	139.3	10.07	8.32	2.44	3.27	3.43	3.46	44.50	91.98	112.50	114.62
B_7: PSB + VAM	68.8	137.1	9.99	8.24	2.41	3.15	3.38	3.39	44.37	90.53	110.63	112.22
B_8: *Rhizobium spp.* + PSB + VAM	70.2	140.0	10.16	8.41	2.48	3.35	3.62	3.65	45.23	94.36	115.83	117.90
SEm ±	1.7	3.4	0.20	0.18	0.05	0.06	0.08	0.08	0.58	1.29	1.49	1.37
CD at 5%	NS	NS	NS	NS	0.14*	0.17*	0.23*	0.25*	1.69*	3.75*	4.32*	3.98*

**Significant at p≤ 0.05; NS- Non-significant at p>0.05; PSB- Phosphorus Solubilizing Bacteria; VAM- Vesicular Arbuscular Mycorrhizae*

Table 2: Effect of tillage and biofertilizers on yield, yield attributes and economics of faba bean

Treatments	Pod length (cm)	Pods per plant (no.)	Seeds per pod (no.)	100-seed weight (g)	Seed yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)	Cost of Cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C
Tillage method											
T_1: Conventional Tillage	5.16	25.64	2.93	25.85	2672	3931	40.01	32795	53448	20652	1.63
T_2: Zero Tillage	5.37	28.71	3.08	26.04	3286	4839	40.32	26185	65728	39542	2.51
SEm ±	0.04	0.42	0.02	0.29	38	51	0.32				
CD at 5%	0.13*	1.23*	0.07*	NS	110*	147*	NS				
Biofertilizers inoculations											
B_1: Control (No inoculation)	5.00	23.83	2.83	25.60	2,598	3,976	39.83	29190	51957	22766	1.82
B_2: *Rhizobium spp.*	5.27	27.04	2.97	25.83	2,861	4,195	39.97	29390	57213	27822	2.00
B_3: PSB	5.16	24.15	2.89	25.63	2,558	3,988	40.05	29390	53167	23776	1.85
B_4: VAM	5.22	26.72	2.96	25.70	2,781	4,026	40.07	29390	55615	26224	1.95
B_5: *Rhizobium spp.* + PSB	5.31	27.13	3.04	26.03	2,983	4,371	40.17	29590	59667	30076	2.06
B_6: *Rhizobium spp.* + VAM	5.36	30.09	3.14	26.30	3,347	4,914	40.27	29590	66933	37343	2.32
B_7: PSB + VAM	5.34	27.65	3.06	26.12	3,186	4,646	40.53	29590	63717	34126	2.20
B_8: *Rhizobium spp.* + PSB + VAM	5.45	30.80	3.17	26.37	3,422	4,966	40.45	29790	68433	38643	2.35
SEm ±	0.09	0.85	0.05	0.58	76	101	0.65				
CD at 5%	0.26*	2.46*	0.14*	NS	219*	294*	NS				

**Significant at p≤ 0.05; NS- Non-significant at p>0.05; PSB- Phosphorus Solubilizing Bacteria; VAM- Vesicular Arbuscular Mycorrhizae*

Table 3: Effect of tillage and biofertilizers on growth indices of faba bean

Treatments	Absolute growth rate (g/day)			Crop growth rate (g/m²/day)			Relative growth rate (mg/g/day)		
	0-60 DAS	61-90 DAS	91 DAS-Harvest	0-60 DAS	61-90 DAS	91 DAS-Harvest	0-60 DAS	61-90 DAS	91 DAS-Harvest
Tillage method									
T1: Conventional Tillage	0.64	1.43	3.27	1.41	3.18	7.28	60.70	146.48	101.08
T2: Zero Tillage	0.65	1.50	3.48	1.44	3.34	7.73	61.03	147.67	102.08
SEm ±	0.01	0.02	0.04	0.01	0.04	0.08	0.12	0.21	0.16
CD at 5%	NS	0.05*	0.11*	NS	0.11*	0.24*	NS	0.61*	0.46*
Biofertilizers inoculations									
B1: Control (No inoculation)	0.63	1.31	2.90	1.39	2.92	6.45	60.40	144.74	99.34
B2: Rhizobium spp.	0.64	1.46	3.22	1.42	3.24	7.15	60.80	146.91	101.02
B3: PSB	0.63	1.32	2.92	1.40	2.94	6.50	60.56	144.97	99.50
B4: VAM	0.64	1.44	3.10	1.42	3.19	6.88	60.72	146.60	100.47
B5: Rhizobium spp. + PSB	0.65	1.48	3.48	1.43	3.29	7.72	60.92	147.30	102.06
B6: Rhizobium spp. + VAM	0.66	1.57	3.79	1.46	3.48	8.43	61.18	148.58	103.38
B7: PSB + VAM	0.65	1.52	3.67	1.44	3.38	8.14	61.04	147.89	102.83
B8: Rhizobium spp. + PSB + VAM	0.66	1.65	3.94	1.47	3.66	8.76	61.31	149.63	104.03
SEm ±	0.01	0.04	0.07	0.02	0.08	0.16	0.24	0.42	0.32
CD at 5%	NS	0.1*	0.22*	NS	0.23*	0.49*	NS	1.23*	0.92*

**Significant at p≤ 0.05; NS- Non-significant at p>0.05; PSB- Phosphorus Solubilizing Bacteria; VAM- Vesicular Arbuscular Mycorrhizae*

100-seed weight did not differ significantly with tillage, probably due to genetic determination of seed weight, which does not easily alter with agronomic intervention. The data given in table 2 showed that various yield attributes *viz.,* seeds/pod (no.), pods/plant (no.), pod length (cm), at harvest, were recorded maximum in *Rhizobium spp.* + PSB + VAM closely followed by *Rhizobium spp.* + VAM, which was significantly higher than control, in which the lowest values for all the yield attributes were noted. The seed inoculation with *Rhizobium spp.* + PSB + VAM produced maximum seed and straw, which were statistically indifferent with *Rhizobium spp.* + VAM but significantly superior to control. All the biofertilizer treatments were found to improve the seed and straw yield over control (table 2) Similar findings had been reported by [12]. The maximum seed and straw yield (kg/ha) were recorded with *Rhizobium spp*. + PSB + VAM (3422,4966 respectively) while the minimum straw yield was obtained in the control (2598, 3976 respectively) thus getting a significant increase of 824 kg/ha and 990 kg/ha respectively. Seed inoculation with biofertilizers failed to cause any significant variation in 100-seed weight. The cumulative effect of an increase in yield attributing characters may be attributed to higher seed and straw yield.

Rhizobium and VAM augment growth of legumes in conjunction with enhancing microbial activity in soil rhizosphere, VAM colonizes the root of plants and aid in better nutrient uptake and maintain soil aggregate structure[13], strengthening macropore structure of soil for easy water and air movement and thereby helps in improving yield[14].

Economic analysis: The data showing the economics of various treatments is shown in table 2. The cost of cultivation (₹/ha) under ZT (26185) was observed 20% less in comparison to CT (32795). While, higher net returns (₹/ha), gross returns (₹/ha) and B:C were realized under ZT (39542, 65728 and 2.51) over CT (20652, 53448, and 1.63) by an increment of ₹18890, ₹12280, and 0.88, respectively. These findings are in line with [15] and [16]. Maximum net returns (₹38643/ha), gross returns (₹68433/ha) and B:C (2.35) were realized in *Rhizobium spp.* + PSB + VAM which were higher by 15877 ₹/ha , ₹16476, and 0.53, respectively over control. Similar results have been reported in summer mungbean by [17] and in cowpea by [18].

In conclusion, zero tillage recorded higher growth attributes (plant height, number of branches per plant and growth indices), yield attributes (pod length, seeds per pod, pods per plant, and 100-seed weight) and yields (seed and straw) of faba bean as well as better economic returns over conventional tillage. Among biofertilizer inoculations, *Rhizobium spp.* + PSB + VAM recorded the highest values of all these parameters over rest of the treatments.

FUTURE SCOPE OF STUDY

The present study demonstrated the superiority of zero tillage combined with multiple biofertilizer inoculations in improving growth, yield, and profitability of faba bean. However, long-term field experiments are required to validate these findings across different soil types, climatic conditions, and cropping systems. Future research should also focus on soil microbial dynamics, nutrient-use efficiency, and environmental impacts such as carbon sequestration and greenhouse gas mitigation under zero tillage with biofertilizer integration. Additionally, the potential of integrating biofertilizers with organic amendments or precision nutrient management strategies should be explored to enhance sustainability and resilience in pulse-based cropping systems.

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DISCLOSURE OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research article.

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