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Enhancement in Growth and Yield of Mungbean [*Vigna radiata* (L.) Wilczek] through Phosphorus Management by Using PROM and Microbial Inoculants

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Abstract

A 2024 field study at Vivekananda Global University, Jaipur, evaluated phosphorus management in mungbean on loamy sand soil using a randomized block design with 12 treatments, including Phosphate Rich Organic Manure (PROM), Phosphate Solubilizing Bacteria (PSB), Vesicular Arbuscular Mycorrhiza (VAM), Pseudomonas Fluorescens (PF), and their combinations. The mungbean variety IPM-02-3 showed enhanced growth and yield parameters with PROM and microbial inoculants. The combination of PROM + PSB + VAM + PF (T12) yielded the highest grain (1339 kg/ha), straw (2702 kg/ha), and biological yields (4041 kg/ha), up 58.7%, 65.7%, and 63.2% over the control, respectively, and was comparable to PROM + PSB + VAM (T9). Economically, T12 gave the highest net returns (Rs. 82,378/ha), while T9 was similarly profitable. PSB alone had the highest benefit-cost ratio (1.68). Both T12 and T9 improved post-harvest soil N and P availability. Although T12 recorded the highest grain yield (1339 kg ha^{-1}) and net returns (Rs. 82,378 ha^{-1}), T9 (PROM + PSB + VAM) produced statistically comparable grain yield (1297 kg ha^{-1}) and economic returns. Therefore, T9 may be considered a cost-effective alternative where additional inoculation with Pseudomonas fluorescens is not economically justified.

Keywords: Mungbean, Phosphorus, PROM, PSB, Vesicular Arbuscular Mycorrhiza (VAM), Pseudomonas Fluorescens (PF)

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Introduction

Pulses are a cornerstone of Indian agriculture and diets, especially for vegetarian populations, providing an affordable protein source (approximately 14% of dietary protein) [1]. India, the world's leading pulse producer and consumer, contributes 25–28% of global production. Mungbean (*Vigna radiata*), a vital kharif pulse crop grown in arid and semi-arid regions, is valued for its high protein (25%), lysine, and tryptophan content, along with vitamins, minerals, and carbohydrates [2]. Its versatility allows consumption as sprouted seeds, flour, or fodder. In 2022–23, India's pulse cultivation spanned 28.90 million hectares, yielding 26.06 million tonnes, with mungbean covering 5.18 million hectares and producing 3.13 million tonnes at 598 kg/ha [3]. In Rajasthan, mungbean occupies 2.33 million hectares, yielding 1.175 million tonnes at 504 kg/ha. However, low productivity persists due to poor fertilizer use, marginal lands, rainfed conditions, pests, diseases, weeds, and limited access to improved varieties [4]. Previous studies have generally evaluated PROM, PSB, VAM, or Pseudomonas fluorescens individually or in limited combinations. The present investigation evaluated the integrated effect of PROM, PSB, VAM, and Pseudomonas fluorescens under semi-arid conditions of Rajasthan and compared twelve treatment combinations. The study also assessed growth, nodulation, yield, economics, and post-harvest soil fertility, thereby providing a comprehensive evaluation of integrated phosphorus management in mungbean.

As a legume, mungbean requires minimal nitrogen due to biological nitrogen fixation by bacteria like Rhizobium [6], but phosphorus is critical for growth, nodulation [7], and yield. Indian soils often lack sufficient phosphorus, with only 30% of applied phosphorus available to crops, the rest becoming insoluble [8]. Excessive chemical phosphatic fertilizers degrade soil health and the environment, prompting a shift to sustainable alternatives like Phosphate Rich Organic Manure (PROM) and microbial inoculants. PROM, a cost-effective blend of composted manure and rock phosphate, enhances phosphorus availability, especially in saline soils [9]. Phosphate-solubilizing bacteria (PSB), such as Bacillus and Pseudomonas, and vesicular-arbuscular mycorrhiza (VAM) improve phosphorus uptake, crop yields (by 10–30%), and soil fertility [10]. Plant growth-promoting rhizobacteria (PGPR), like Pseudomonas Fluorescens, further enhance nutrient mobilization and disease resistance [11, 12]. Integrating PROM, PSB, VAM, and PGPR offers a sustainable strategy to optimize phosphorus management, boost mung bean productivity, and maintain soil health.

Materials and Methods

The field experiment was conducted during the Kharif season of 2024 at the Agronomy Research Farm, Vivekananda Global University, Jaipur (Rajasthan, India). The site lies in the semi-arid region with loamy sand soils, low organic carbon (0.32%), available nitrogen (122.5 kg ha^{-1}), medium phosphorus (16.44 kg ha^{-1}), potassium (152. kg /ha) and low available zinc (0.55 ppm) and iron (3.67 ppm). The soil pH was neutral (pH 6.97) the experimental season received 490 mm rainfall, mostly concentrated between July and September. The average maximum and minimum temperatures during crop growth were 30.5-38.1°C and 17.6-24.9°C, respectively, suitable for mung bean cultivation.

Experimental Design and Treatments

The experiment was laid out in a Randomized Block Design (RBD) with 12 treatments replicated thrice. The treatments were as follows: 1. Control (T1), 2.PROM (T2), 3. PSB (T3), 4. VAM (T4), 5.Pseudomonas Fluorescens (PF)(T5) 6. PROM + PSB(T6). 7. PROM + VAM (T7), 8.PROM + PF (T8), 9. PROM + PSB + VAM (T9), 10.PROM + PSB + PF(T10), 11. PROM + VAM + PF (T11), 12. PROM + PSB + VAM + PF (T12). The Materials and Methods section has been expanded to include: PROM applied @ 500 kg ha^{-1}., Nutrient composition of PROM (available P_2O_5, N, K contents, PSB strain (e.g., Bacillus megaterium, VAM species (e.g., Glomus fasciculatum)., Pseudomonas fluorescens strain details., Cell population of PSB and PF (minimum 10^8 CFU g^{-1})., VAM inoculum containing approximately 100–120 infective propagules g^{-1} and Seed inoculation method and dosage (25 g inoculant kg^{-1} seed).

Observations Recorded- Growth traits: Plant count, Plant height (cm), nodulation (both total and effective), nodule fresh and dry weight, dry matter accumulation (g m^{-2}), leaf area index (LAI), and chlorophyll content (mg g^{-1} fresh weight). Yield attributes and yield : pods per plant, grains per pod, and test weight (g), grain yield (kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}), and harvest index (%). Economics: Cost of cultivation, gross returns, net returns, and B:C ratio.

Statistical Analysis- The data were analyzed using ANOVA for RBD. Critical differences (CD) at 5% probability were calculated for comparing treatment means.

Results and Discussion

Impact on Growth Traits

All treatments significantly enhanced mungbean growth parameters compared to the control (T1), with T12 (PROM + PSB + VAM + PF) consistently achieving the highest values across plant count (11.82 at 25 DAS, 11.22 at harvest), plant height (32.54 cm at 25 DAS, 58.81 cm at 45 DAS, 69.92 cm at harvest), branches (5.96 at 45 DAS, 9.94 at harvest, 46.8% and 41% over T1), dry matter accumulation (36.11 g/m at 25 DAS, 92.74 g/m at 45 DAS, 139.75 g/m at harvest, 52.7% over T1), total root nodules (38.74), effective nodules (33.46), nodule fresh weight (150.17 mg), dry weight (70.78 mg), leaf area index (6.21), and chlorophyll content (3.62 mg/g), driven by synergistic effects of microbial inoculants and PROM enhancing phosphorus and nitrogen availability. T9 (PROM + PSB + VAM) was statistically comparable to T12 for most parameters, including plant count (11.96, 11.32), height (32.44 cm, 58.11 cm, 69.02 cm), branches (5.9, 9.73), dry matter (35.92 g/m, 92.53 g/m, 139.47 g/m), nodules (37.44 total, 32.99 effective), nodule weights (146.7 mg fresh, 69.05 mg dry), LAI (6.19), and chlorophyll (3.54 mg/g), suggesting marginal additional benefits from PF in T12, making T9 a cost-effective alternative. T3 (PSB) showed the highest plant count (12.22, 11.42), likely due to enhanced seedling establishment from phosphorus solubilization (Chen et al., 2006), while T8 (PROM + PF) had the lowest (10.02), possibly due to antagonistic interactions reducing survival. Combined treatments (T6, T7, T8, T10, T11) outperformed single treatments (T2, T3, T4, T5), which still surpassed T1 (lowest values: 10.42 plant count, 45.12 cm height, 7.05 branches, 90.2 g/m dry matter, 28.07 total nodules, 23.11 effective nodules, 122.8 mg fresh weight, 56.67 mg dry weight, 4.08 LAI, 2.2 mg/g chlorophyll), highlighting the role of VAM, PSB, and PROM in mitigating phosphorus fixation and boosting photosynthesis, nodulation, and plant vigor in low-fertility soils [12] [13] and [14].

Impact on Yield Attributes and Yield Traits

All treatments significantly enhanced mungbean yield attributes and yields compared to the control (T1), with T9 (PROM + PSB + VAM) recording the highest number of pods per plant (43.12, an 83.3% increase over T1's 23.52), grains per pod (10.57, statistically at par with T12's 10.31 and T10's 10.04, versus T1's 8.39), and test weight (43.00

g, comparable to T12's 42.27 g and T10's 41.64 g, versus T1's 36.00 g), attributed to enhanced phosphorus availability and nitrogen fixation from VAM and PSB, which promote pod formation and seed development (Kasturikrishna and Ahlawat, 1999; Zhang et al., 2014). T12 (PROM + PSB + VAM + PF) achieved the highest grain yield (1339 kg/ha, 58.6% over T1's 844 kg/ha), straw yield (2702 kg/ha, 65.7% over T1's 1631 kg/ha), and biological yield (4041 kg/ha, 63.3% over T1's 2475 kg/ha), statistically similar to T9 (1297 kg/ha grain, 2650 kg/ha straw, 3947 kg/ha biological) and T10 (grain and straw yields slightly lower but significant), reflecting the synergistic effects of combined microbial inoculants and PROM in improving nutrient uptake and biomass accumulation [11] and [12].

Table 1 Impacts of PROM and microbial inoculants on growth attributes of green gram

S.No.	Treatments	Plant stand/ m row length		Plant height (cm)			Branches/ plant at		Dry matter accumulation (g/m row length) at			Number of nodules/ plant		Weight of nodules/ plant (mg)		LAI	Chlorophyll content (mg/g)
		25 DAS	At harvest	25 DAS	45 DAS	At harvest	45 DAS	Harvest	25 DAS	45 DAS	harvest	Total nodules	Effective nodules	Fresh	Dry weight		
T1	Control	11.62	10.42	22.14	38.21	45.12	4.06	7.05	23.65	61.03	90.2	28.07	23.11	122.8	56.67	4.08	2.2
T2	PROM	11.72	10.62	25.84	46.81	55.62	4.86	8.54	28.88	74.75	111.37	30.37	26.64	137.8	64.92	5	2.71
T3	PSB	12.22	11.42	24.24	43.91	52.12	4.66	8.36	27.15	70.3	104.03	30.27	25.12	129.67	60.88	4.71	2.52
T4	VAM	10.82	10.52	23.54	42.01	49.02	4.56	7.99	25.41	65.84	97.53	30.07	24.78	129.33	60.84	4.45	2.37
T5	Pseudomonas Fluorescens (PF)	11.62	10.22	23.54	41.71	49.12	4.63	8.08	25.38	65.75	97.64	30.14	24.86	129.9	60.69	4.47	2.38
T6	PROM + PSB	11.12	10.52	29.14	52.81	63.42	5.31	9.08	32.43	83.68	125.65	34.6	30.38	139.67	65.41	5.6	3.21
T7	PROM + VAM	11.42	10.62	27.54	48.91	60.02	5.18	8.88	30.69	79.22	118.81	32.37	28.66	139.33	65.23	5.3	3.04
T8	PROM + PF	10.02	10.02	27.44	49.81	59.12	5.16	8.98	30.63	79.21	118.22	32.6	28.34	139	65.06	5.29	2.87
T9	PROM + PSB + VAM	11.96	11.32	32.44	58.11	69.02	5.9	9.73	35.92	92.53	139.47	37.44	32.99	146.7	69.05	6.19	3.54
T10	PROM + PSB + PF	10.92	10.42	30.84	55.11	66.12	5.73	9.39	34.28	88.26	132.58	36.74	32.28	144.67	68	5.99	3.46
T11	PROM + VAM + PF	11.22	10.62	29.24	53.01	62.62	5.5	9.22	32.55	83.78	126.05	34.87	30.52	141	66.1	5.62	3.3
T12	PROM + PSB + VAM + PF	11.82	11.22	32.54	58.81	69.92	5.96	9.94	36.11	92.74	139.75	38.74	33.46	150.17	70.78	6.21	3.62
	CD (p = 0.05)	0.45	0.507	1.38	2.168	2.32	0.258	0.309	1.274	2.961	4.408	0.897	1.045	6.433	2.411	0.26	0.168
	SEm+	0.152	0.172	0.468	0.734	0.786	0.087	0.105	0.432	1.003	1.493	0.304	0.354	2.179	0.817	0.088	0.057
	CV (%)	2.322	2.792	2.958	2.591	2.329	2.955	2.07	2.471	2.225	2.215	1.593	2.157	2.745	2.194	2.908	3.369

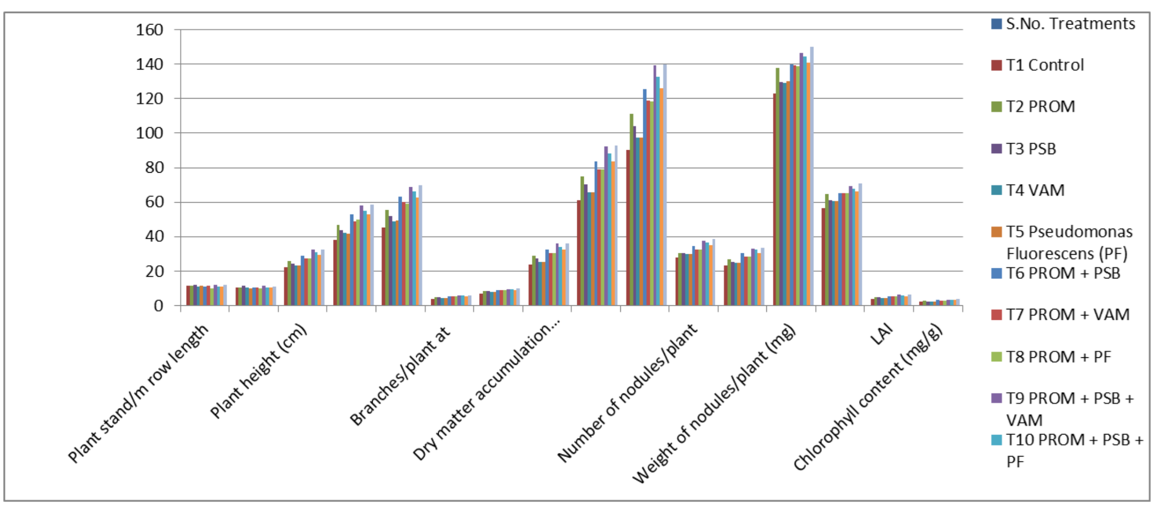

Figure 1 Impacts of PROM and microbial inoculants on growth attributes of green gram

Table 2 Impacts of PROM and microbial inoculants on yield and yield attributes

S.No.	Treatments	Yield attributes			Yield (kg/ha)				Economics			
		Number of pods/plant	Number of grains/pod	Test weight (g)	Grain	Straw	Biological	Harvest index (%)	Cost of cultivation (₹/ha.)	Groos return (₹./ha.)	Net returns (₹/ha)	B:C ratio
T1	Control	23.52	8.39	36	844	1631	2475	34.1	38800	82484	43684	1.12
T2	PROM	32.8	9.23	38.68	1050	2066	3116	33.69	48300	102764	54464	1.13
T3	PSB	30.95	9.04	38.37	974	1860	2834	34.36	38828	95100	56272	1.44
T4	VAM	28.22	8.95	38.44	917	1800	2717	33.75	39800	89730	49930	1.25
T5	Pseudomonas fluores cens (PF)	26.92	8.81	37.17	903	1761	2664	33.89	38912	88314	49402	1.26
T6	PROM + PSB	37.39	9.82	41.37	1199	2399	3598	33.32	48328	117506	69178	1.43
T7	PROM + VAM	35.11	9.46	39.68	1138	2269	3407	33.4	49300	111496	62196	1.26
T8	PROM + PF	34.19	9.5	38.74	1107	2195	3302	33.52	48412	108410	59998	1.23
T9	PROM + PSB + VAM	43.12	10.57	43	1297	2650	3947	32.86	48428	127330	78902	1.62
T10	PROM + PSB + PF	40.49	10.04	41.64	1280	2556	3836	33.36	48440	125424	76984	1.58
T11	PROM + VAM + PF	38.22	10.1	40.46	1222	2431	3653	33.45	48912	119704	70792	1.44
T12	PROM + PSB + VAM + PF	41.8	10.31	42.27	1339	2702	4041	33.13	48940	131318	82378	1.68
	CD (p = 0.05)	1.1	0.384	1.771	38.57	97.516	120.925	N/A	1989.137	4012.32	2522.324	0.08
	SEm+	0.373	0.13	0.6	13.07	33.036	40.966	0.502	673.867	1359.267	854.496	0.027
	CV (%)	1.877	2.368	2.621	2.047	2.609	2.151	2.593	2.568	2.174	2.355	3.439

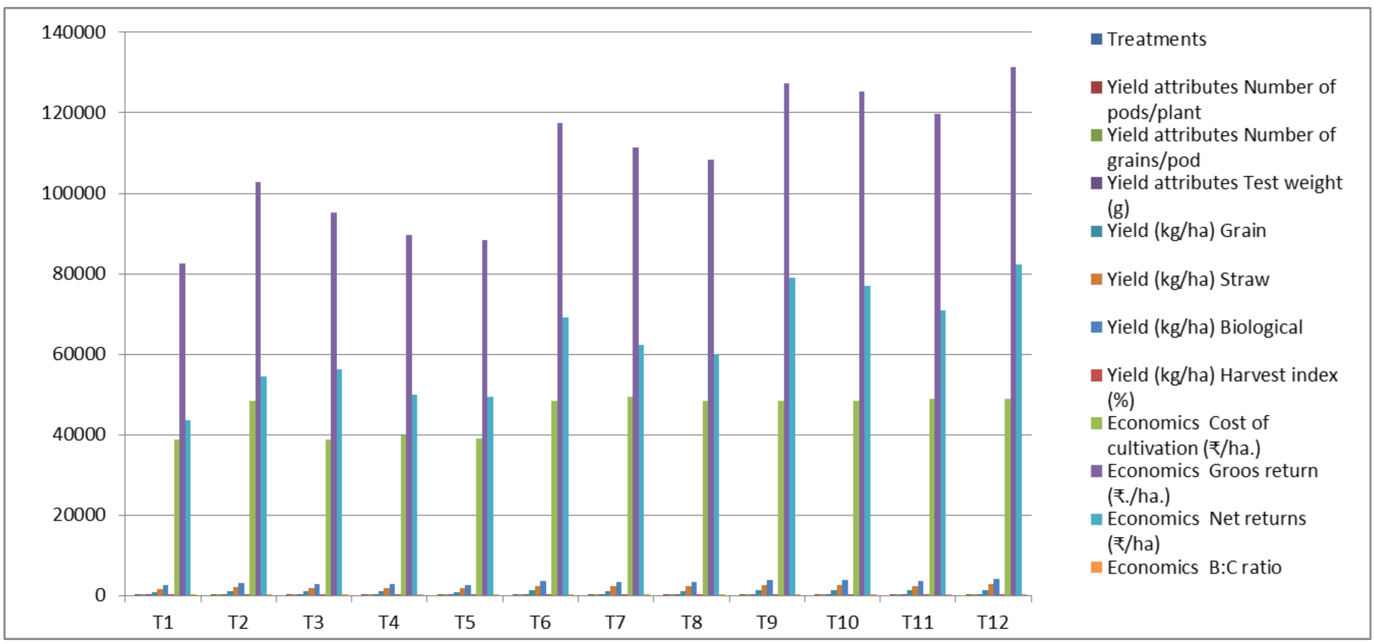

Figure 2 Impacts of PROM and microbial inoculants on yield attributes, yield and economics

Economic Analysis

All treatments increased the cost of cultivation from Rs. 38,800/ha to Rs. 48,940/ha due to the addition of bio-inoculants, but these costs were offset by significantly higher returns. Treatment T12, which combined PROM, PSB, VAM, and PF, yielded the highest gross returns at Rs. 131,318/ha and the highest net returns at Rs. 82,378/ha. The superior economic performance of combined treatments like T12 and T9, which showed B:C ratios of 1.68 and 1.62 respectively, highlights their profitability and effectiveness in enhancing yield and returns compared to the control and single-application treatments.

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Conclusion

Based on the one-year field study, integrated phosphorus management through PROM and microbial inoculants significantly improved growth, nodulation, yield attributes, yield, and profitability of mungbean. The treatment T12 (PROM + PSB + VAM + Pseudomonas fluorescens) recorded the highest grain yield (1339 kg ha^{-1}), biological yield (4041 kg ha^{-1}), and net returns (Rs. 82,378 ha^{-1}). However, T9 (PROM + PSB + VAM) produced statistically comparable grain yield (1297 kg ha^{-1}) and economic returns, indicating that the additional benefit obtained from Pseudomonas fluorescens inoculation was relatively small. Therefore, T12 may be recommended for maximizing productivity, whereas T9 can be considered a more economical and practical option for farmers under similar agro-climatic conditions. Further multi-season studies are required to validate these findings.

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