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Effect of Graded Levels of Phosphorus & Phosphorus Solubilizing Microorganisms on Growth and Yield of Green Gram (*Vigna radiata* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The present investigation entitled "Effect of Graded Levels of Phosphorus and Phosphorus Solubilizing Microorganisms on Growth and Yield of Green gram" during kharif season of the year, 2022-2023 at the research farm of the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Latur. The experiment was layout in FRBD with three replications and a recommended variety of green gram BM 2003-2 as a test crop along with twelve treatments. The results in nutshell indicated that the growth and yield were significantly influenced by the application of 125% RDP, combined with Aspergillus awamori. The growth parameters viz., plant height, number of leaves & no. of nodules plant-1, significantly increased with application of 125 % RDP, combined with Aspergillus awamori. The combined approach of incorporating phosphate-solubilizing microorganisms, particularly Aspergillus awamori, with the application of 125% RDP,

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resulted in a noteworthy increase in the availability of nitrogen (N), phosphorus (P), and potassium (K) in the soil. This improvement was attributed to the enhanced solubilization of inorganic phosphorus and the secretion of organic acids, which facilitated an increase in the content of other essential nutrients in the soil. The nutrient content in both grain and straw exhibited significant increases due to seed inoculation with Aspergillus awamori in conjunction with the application of 125%RDP. This approach outperformed treatments involving Tricoderma viridae and Bacillus megaterium in combination with 100% RDP, and the control. The incorporation of phosphate-solubilizing microorganisms, particularly Aspergillus awamori, alongside the application of 125% RDP, proved to be significantly more effective than treatments involving a Tricoderma viridae with 100% RDP, as well as the control.

Keywords: PSM; 125% RDP; aspergillus awamori; Tricoderma viridae; Bacillus megaterium; higher uptake of NPK.

1. INTRODUCTION

India leads the world in pulse production, contributing a remarkable 25% to the global output. Pulses, constituting a crucial component of India's agricultural economy, rank second only to food grains and oilseeds in terms of acreage, production, and economic value [1]. Beyond their economic significance, pulses play a vital role in fostering a nutritionally balanced diet, particularly serving as a primary source of dietary protein for the vegetarian population. The international recognition of pulses was underscored by the 68th UN General Assembly, which declared 2016 as the **"International Year of Pulses"** highlighting their importance in promoting nutritious food for a sustainable future. India's dominance in green gram cultivation is evident, with major production concentrated in states such as Andhra Pradesh, Maharashtra, Orissa, Rajasthan, Gujarat, Punjab, and Uttar Pradesh. Overall, India leads globally in both the area and production of essential pulses, with approximately 290 million hectares under pulse cultivation, yielding 28 million metric tonnes and a productivity rate of 764 kg per hectare. Green gram, covering an area of about 3.57 million hectares, contributes significantly to this, with a total production of 17.89 metric tonnes and a productivity rate of 500 kg per hectare [2]. In the realm of nutrient management, particularly for pulses like green gram, phosphorus emerges as a critical element. Often referred to as the "**master key element**" in crop production, phosphorus plays a pivotal role in root development, *Rhizobia* availability, and nitrogen fixation.

The application of phosphorus to legumes proves essential for energy transfer, photosynthesis, carbohydrate and fat metabolism, as well as nutrient movement within the plant [3]. Despite its importance, the challenge lies in the fact that only 25% to 30% of applied phosphorus is available to crops, with the remainder converting into insoluble forms. This deficiency is a major factor contributing to suboptimal yields of mung bean in various soil types. Recognizing the importance of phosphorus solubilizing microorganisms (PSM), biofertilizers are considered a cost-effective and eco-friendly solution to enhance phosphorus availability. Inoculating pulse seeds with PSM aims to increase their presence in the rhizosphere, thereby substantially improving phosphorus availability for plant growth [4]. Biofertilizers are living organisms that enhance plant nutrients, providing a cost-effective, eco-friendly, and renewable source of non-bulky, low-cost supplements for sustainable agriculture. The inoculation of pulses' seeds with phosphorous solubilizers aims to boost their presence in the rhizosphere, leading to a substantial increase in phosphorus availability for plant growth. In soil, phosphorus often exists in an unavailable form, but efficient microorganisms such as bacteria, fungi, and cyanobacteria play a crucial role in making it accessible. Phosphate solubilizing microorganisms, such as *Aspergillus* and *Bacillus,* play a crucial role in solubilizing soil phosphorus through mechanisms like pH reduction and organic acid secretion [5]. Experiments focused on the synergistic effects of phosphorus and PSM application have demonstrated enhanced phosphorus uptake by plants, showcasing the potential of PSM in solubilizing phosphates and mobilizing phosphorus in crop plants. In conclusion, understanding the intricate relationship between phosphorus, green gram cultivation, and the role of PSM in sustainable agriculture is vital. Phosphate-solubilizing microorganisms contribute by secreting various organic acids (citric, oxalic, tartaric, acetic, maleic, fumaric, etc.), which dissolve insoluble mineral phosphate through mechanisms like pH reduction, chelation with metal ions (Ca, Fe, Al), and exchange reactions. This process makes phosphorus available to plants. Soil microorganisms are particularly effective in releasing phosphorus from both inorganic and organic pools of total soil phosphorus through solubilization and mineralization.

2. MATERIALS AND METHODS

The present investigation entitled "Effect of graded levels of phosphorus and phosphorus solubilizing microorganisms (PSM) on growth, nutrient uptake, yield & quality of Green gram. (*Vigna radiata* L.)" was conducted during *kharif* season of the year 2022-2023. The details of the materials and methods adopted for raising the crop for evaluation of treatments during the studies are enclosed.

Latur district of Maharashtra state is situated between 18°05'-18°75' North latitude and between 76°25' to 77°25' East longitude on the Balaghat plateau with a mean sea level height 633.85 meters and derived from deccan trap. Rock, is basaltic in nature rich in Magnesium and dominated by smectite minerals. This area falls under assured rainfall zone. The annual average precipitation is 750 to 800 mm. Most of the rains are received during July to October from South-West monsoon.

The black soils of Latur district of Marathwada region were formed from the weathering of trap rock and are rich in iron, lime and magnesia but they vary widely both in texture and depth. These soils were classified as clayey, smectite and isohyperthermic having very gently sloping with moderate erosion. The physiographic position of soil is north deccan upper plateau. The soils were dark grey to brown in colour with sufficient calcium carbonate.

The experimental soil was clayey in texture, calcareous in nature, moderately alkaline reaction, low in content of organic carbon (4.60 g kg^{-1}), $CaCO_3$ (63.00 g kg^{-1}) available nitrogen (178.34 kg ha^{-1}), available phosphorous (12.98 kg ha^{-1}), medium in available potassium (292.56 mg kg^{-1}), deficient in DTPA zinc (0.59 mg kg^{-1}) and DTPA iron (1.475 mg kg^{-1}).

Soil pH (7.974) was determined by 1:2.5 soil water suspension ratio using a digital pH meter described by Jackson [6]. Electrical conductivity (0.34 dSm^{-1}) of soil was determined by 1:2.5 soil: water suspension ratio using the Conductivity Bridge described by Jackson [6]. Soil organic carbon (4.6 gkg^{-1}) was determined by modified method of Walkley and Black [7]. The calcium carbonate (63.00 g kg^{-1}) content in soil was determined by Rapid titration method by [8]. Available nitrogen (178.34 kg ha^{-1}) was determined by alkaline potassium permanganate method as described by Subbiah and Asija [9]. Available phosphorus (12.98 kg ha^{-1}) was extracted from the soil with 0.5 M Sodium bicarbonate by Olsen's method as described by Jackson [6]. Available potassium (292.56 kg ha^{-1}) was determined with neutral normal ammonium acetate and potassium in the extract was determined on Flame Photometer [8].

3. RESULTS AND DISCUSSION

3.1 Response of Phosphate Solubilizing Microorganism and phosphorus Levels on Growth Parameters Green Gram

Growth characters *viz*. plant height, number of leaves, no. of nodules $plant^{-1}$.

were recorded during the course of the field experiment and the results obtained with the application of phosphorus levels and phosphorus solubilizing microorganisms are described here.

3.1.1 Plant height

The recorded plant height at 30, 45 days after sowing (DAS), and during crop harvest is presented in Tables (1 and 2) and depicted in Fig. 1. The findings indicate a noticeable impact on plant height attributed to the utilization of Phosphorus and Phosphorus Solubilizing Microorganisms during critical growth stages of the crop.

Among the treatments, the most remarkable plant height was observed in T_{10} (M1 P3: Inoculation of *Aspergillus awamori* + 125% RDP), displaying the tallest measurements at 30 DAS (33.45 cm), 45 DAS (50.52 cm), and during harvest (61.21 cm), significantly surpassing all other treatments. Conversely, treatment M_2P_0 exhibited the lowest plant height at 30 DAS (26.24 cm), 45 DAS (33.98 cm), and during harvest (40.05 cm) in the green gram crop.

Table 1. Effect of levels of phosphorus and phosphorus solubilizing microorganisms on plant height (cm) of green gram at 30, 45 DAS and at harvest

Treatment	Phosphorus Level		
	30 DAS	**45 DAS**	**AT HARVEST**
Microorganisms (M)			
M_1	30.16	43.74	53.9
M_2	28.45	38.63	46.48
M_3	28.61	41.17	50.14
SE(±)	**0.336**	**0.554**	**0.633**
CD at 5 %	**0.988**	**1.626**	**1.858**
Phosphorus (P)			
P_0	26.02	35.08	42.22
P_1	27.61	38.96	47.55
P_2	30.68	43.62	53.91
P_3	31.99	47.09	57.7
SE(±)	**0.554**	**0.64**	**0.731**
CD at 5%	**1.626**	**1.877**	**2.145**
M × P			
SE(±)	**0.67**	**1.109**	**1.267**
CD at 5%	**1.97**	**3.25**	**3.716**

Table 2. Interaction of levels of phosphorus and phosphorus solubilizing microorganisms on plant height (cm) of green gram at 30, 45 DAS and at harvest

	Phosphorus levels				
PSM	**P0**	**P1**	**P2**	**P3**	**MEAN**
PLANT HEIGHT AT 30 DAS					
M_1	26.70	28.17	32.34	33.45	**30.16**
M_2	26.24	27.00	29.56	31.02	**28.45**
M_3	25.12	27.67	30.15	31.50	**28.61**
Mean	**26.02**	**27.61**	**30.68**	**31.99**	
	M		**P**		**M × P**
SE (±)	**0.336**		**0.388**		**0.67**
CD at 5%	**0.988**		**1.139**		**1.97**
PLANT HEIGHT AT 45 DAS					
M_1	36.11	40.89	47.87	50.12	**43.74**
M_2	33.98	37.86	38.21	44.50	**38.63**
M_3	35.15	38.13	44.78	46.65	**41.17**
Mean	**35.08**	**38.96**	**43.62**	**47.09**	
	M		**P**		**M × P**
SE (±)	**0.554**		**0.64**		**1.109**
CD at 5%	**1.626**		**1.877**		**3.25**
PLANT HEIGHT AT HARVEST					
M_1	44.13	49.74	60.52	61.21	**53.9**
M_2	40.05	45.78	47.78	52.34	**46.48**
M_3	42.50	47.14	53.45	57.50	**50.14**
Mean	**42.22**	**47.55**	**53.91**	**57.7**	
	M		**P**		**M × P**
SE (±)	**0.633**		**0.731**		**1.267**
CD at 5%	**1.858**		**2.145**		**3.716**

The interaction effect of phosphorus solubilizing microorganisms and phosphorus levels showed a significant effect on plant height at 30, 45 DAS and at harvest. The noticeable enhancement in plant height is presumably linked to the application of Phosphorus and Phosphorus Solubilizing Microorganisms in conjunction with RDP in the green gram crop. This application potentially stimulated various enzymes responsible for crucial metabolic activities within the crop, aiding in chlorophyll synthesis, maintaining chloroplast structure, and facilitating essential functions, consequently contributing to increased plant growth.

Similar results were recorded by Heisnam et al. (2017) who noted that the application of T7 treatment (PSM + rhizobium + 40 kg P2O5 ha-1) significantly increased plant height in a green gram by 32 cm at 30 DAS, 51.32 cm at 45 DAS and 62.56 cm at harvest as compared to other treatments.

3.1.2 Number of leaves

The data regarding the number of leaves plant^{-1} of a green gram as influenced by soil application of Phosphorus and Phosphorus Solubilizing Microorganisms was recorded during growth stages presented in Tables (3 and 4) and depicted in Fig. 2.

The treatment T_{10} (*Aspergillus awamori* + 125 % RDP) resulted in the highest number of leaves per plant at 30 DAS (18.30), 45 DAS (30.56), and at harvest (15.64), a performance on par with treatment T_7 (*Aspergillus awamori* + 100 % RDP) and significantly outperforming the other treatments. Conversely, the treatment T_2 (*Bacillus megaterium* + control) recorded the lowest number of leaves per plant at 30 DAS (11.00), 45 DAS (20.60), and at harvest (10.87) for the green gram crop.

The interaction effect of phosphorus solubilizing microorganisms and phosphorus levels showed a significant effect on no. of leaves at 30, 45 DAS and at harvest. The increase in the number of leaves per plant might be attributed to the optimal nutritional support provided to the green gram crop through the application of Phosphorus and Phosphorus Solubilizing Microorganisms. These nutrients are essential for overall plant growth, development, and are directly involved in crucial processes such as photosynthesis and chlorophyll synthesis.

3.1.3 Number of root nodules

The data about the number of root nodules per plant are presented in Tables (5 and 6) and depicted in Fig. 3. It is evident from the data that the number of root nodules per plant in green gram was notably impacted at 45 days by the seed inoculation of phosphate solubilizing microorganisms. The count of root nodules per plant varied between 13.33 to 19.80 at 45 DAS. The findings indicate that the highest count of root nodules, reaching 17.50 per plant, was observed with the seed inoculation of *Aspergillus awamori*, followed by a decrease to 16.46 with *Trichoderma viridae* and 16.13 with *Bacillus megaterium* at 45 DAS. Conversely, the minimum count of nodules per plant, 13.33, was observed in the control at 45 days.

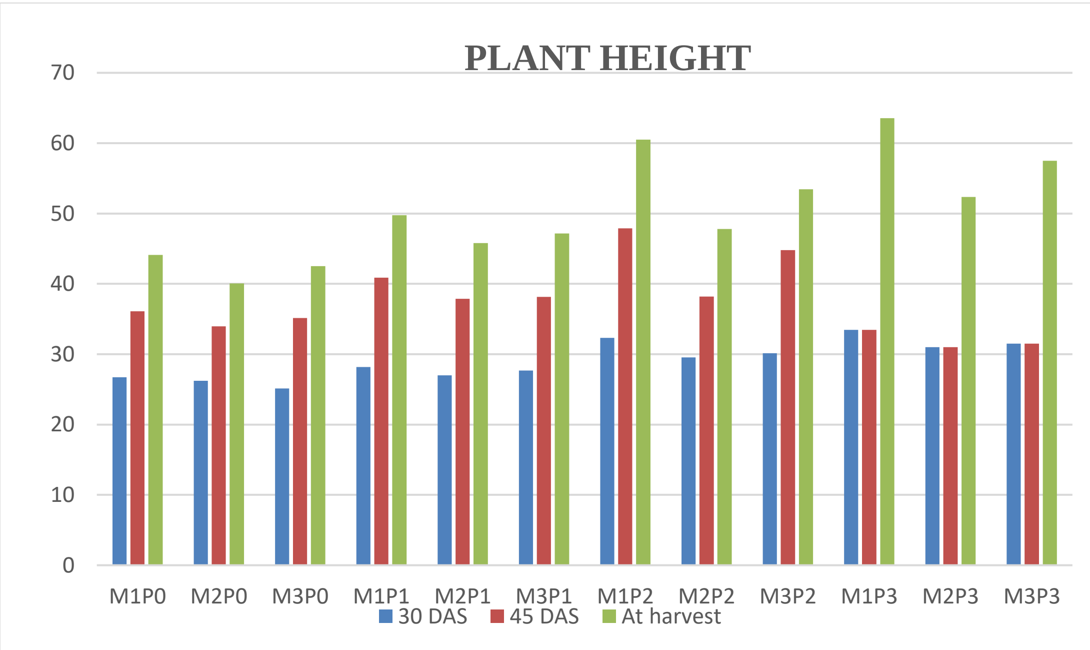

Fig. 1. Effect of phosphate solubilizing microorganisms and phosphorus levels on plant height (cm) of green gram at 30, 45 DAS and at harvest

Table 3. Effect of phosphorus and phosphorus solubilizing microorganisms' application on number of leaves (plant^{-1}) of a green gram at 30, 45 DAS and at harvest

Treatment	Phosphorus Level		
	30 DAS	**45 DAS**	**AT HARVEST**
Microorganism (M)			
M_1	16.17	26.54	14.4
M_2	13.93	23.88	13.56
M_3	15.03	24.77	14.01
SE (±)	**0.333**	**0.333**	**0.333**
CD at 5 %	**0.978**	**0.978**	**0.978**
Phosphorus (P)			
P_0	12.30	21.2	11.69
P_1	14.58	23.21	14.13
P_2	16.38	27.19	14.95
P_3	17.12	28.67	15.28
SE (±)	**0.385**	**0.385**	**0.385**
CD 5%	**1.129**	**1.129**	**1.129**
M × P			
SE (±)	**0.667**	**0.667**	**0.667**
CD at 5%	**1.995**	**1.995**	**1.995**

Table 4. Interaction of phosphorus and phosphorus solubilizing microorganisms' application on a number of leaves (plant^{-1}) of a green gram at 30, 45 DAS and at harvest

	Phosphorus levels				
PSM	**P0**	**P1**	**P2**	**P3**	**MEAN**
No. of leaves 30 DAS					
M_1	13.87	14.98	17.56	18.30	**16.17**
M_2	11.00	14.00	15.36	15.36	**13.93**
M_3	12.05	14.78	16.24	17.07	**15.03**
Mean	**12.30**	**14.58**	**16.38**	**17.12**	
	M		**P**		**M ×P**
SE (±)	**0.333**		**0.385**		**0.667**
CD at 5%	**0.978**		**1.129**		**1.995**
No. of leaves at 45 DAS					
M_1	21.65	24.30	29.68	30.56	**26.54**
M_2	20.60	22.00	25.50	27.45	**23.88**
M_3	21.35	23.34	26.39	28.00	**24.77**
Mean	**21.2**	**23.21**	**27.19**	**28.67**	
	M		**P**		**M ×P**
SE (±)	**0.333**		**0.385**		**0.667**
CD at 5%	**0.978**		**1.129**		**1.995**
No. of leaves at 60 DAS					
M_1	12.45	14.43	15.34	15.64	**14.4**
M_2	10.87	13.75	14.61	15.01	**13.56**
M_3	11.76	14.21	14.92	15.21	**14.01**
Mean	**11.69**	**14.13**	**14.95**	**15.28**	
	M		**P**		**M ×P**
SE (±)	**0.333**		**0.385**		**0.667**
CD at 5%	**0.978**		**1.129**		**1.995**

Further, data indicated that the application of T_{10} (*Aspergillus awamori* + 125 % RDP) significantly increased in root nodules at, 45 green grams. Thus, it is seen that the number of root nodules per plant of green gram increased significantly with every increase in the level of phosphorus.

The significant interaction between phosphate solubilizing microorganisms and phosphorus levels was noted at 45 days. The rise in the number of root nodules per plant in green gram due to the seed inoculation of *Aspergillus awamori* can be attributed to an increase in the availability of soluble phosphorus through the production of organic acids. These acids aid in solubilizing otherwise unavailable phosphate into an accessible form, consequently enhancing nitrogen fixation, thereby resulting in an increased number of root nodules per plant in green gram. Moreover, phosphorus plays a crucial role in nodule initiation and boosts root proliferation, thereby contributing to an increase in the root nodules Similar results were also reported by Vidhyashree et al. [10].

3.2 Response of phosphorus solubilizing microorganism and phosphorus levels on seed and straw yield of green gram

3.2.1 Seed yield

The response of Phosphorus Solubilizing Microorganisms and phosphorus levels on green gram seed yield is presented in Tables no (7 and 8) and depicted in Fig. 4 ranging from 685.85 to 1540.25 kg/ha. Microorganism inoculation, particularly with M_1 (*Aspergillus awamori*), resulted in the maximum seed yield of 1221.95 kg/ha. This was followed by M_3 (*Trichoderma viridea*) with a yield of 1146.94 kg/ha. Different phosphorus levels also led to an increased green gram seed yield. The highest seed yield was achieved with phosphorus levels (P_3) at @ 125% RDP, resulting in 1424.27 kg/ha. This was followed by (P_2) at @100% RDP, with a yield of 1373.08 kg/ha.

The interaction effect between Phosphorus Solubilizing Microorganisms and phosphorus levels on seed yield showed significant results. The increase in seed yield can be attributed to phosphorus's vital role in improving the plant's nutritional status through enhanced photosynthetic activity and nitrogen fixation. Phosphorus also promotes root growth, leading to increased nitrogen renewal by the crop. Phosphate Solubilizing Microorganisms secrete organic acids that may form chelates, effectively solubilizing phosphate, promoting higher nitrogen fixation, rapid growth, improved absorption and utilization of phosphorus and other plant nutrients, ultimately resulting in increased seed yield.

These results are consistent with Singh [11], who concluded that the application of 40 kg P_2O_5/ha through DAP, along with PSB inoculation, significantly increased the highest seed yield (651 kg/ha) of green gram compared to the control. The increased seed yield was due to the improved efficiency of converting insoluble phosphorus into a soluble form.

Yadav [12] revealed that the application of 40 kg P_2O_5/ha + PSB + *Aspergillus awamori* recorded a significantly superior yield of 1583 kg/ha over the control. The increased seed yield was attributed to increased photosynthetic activity, nitrogen fixation, phosphate solubilization, rapid growth, improved nutrient absorption and utilization, ultimately leading to increased seed yield in summer mung bean.

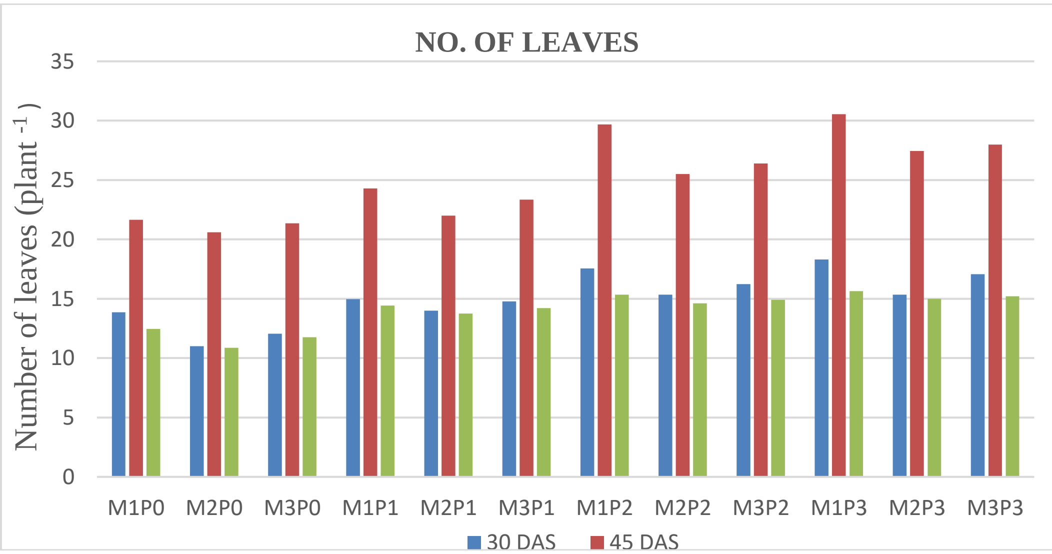

Fig. 2. Effect of phosphate solubilizing microorganisms and phosphorus levels on leaves per plant of a green gram at 30, 45 DAS and at harvest

Table 5. Effect of phosphorus and phosphorus solubilizing microorganisms' application on number of root nodules per plant of green gram

Treatment	
Microorganism (M)	**Root Nodules**
M_1	17.50
M_2	16.13
M_3	16.46
SE (±)	**0.101**
CD at 5%	**0.295**
Phosphorus (P)	
P_0	13.89
P_1	15.74
P_2	18.33
P_3	18.74
SE (±)	**0.116**
CD at 5%	**0.340**
M × P	
SE (±)	**0.201**
CD at 5 %	**0.590**

Table 6. Interaction of phosphorus and phosphorus solubilizing microorganisms' application on number of root nodules per plant of green gram

	Phosphorus levels				
PSM	**P0**	**P1**	**P2**	**P3**	**MEAN**
Number of Root Nodules at 45 DAS					
M_1	14.24	16.56	19.43	19.80	**17.50**
M_2	13.33	15.24	17.73	18.23	**16.13**
M_3	14.10	15.43	18.13	18.20	**16.46**
Mean	**13.89**	**15.74**	**18.33**	**18.74**	
	M		**P**		**M × P**
SE (±)	**0.101**		**0.116**		**0.201**
CD at 5%	**0.295**		**0.340**		**0.590**

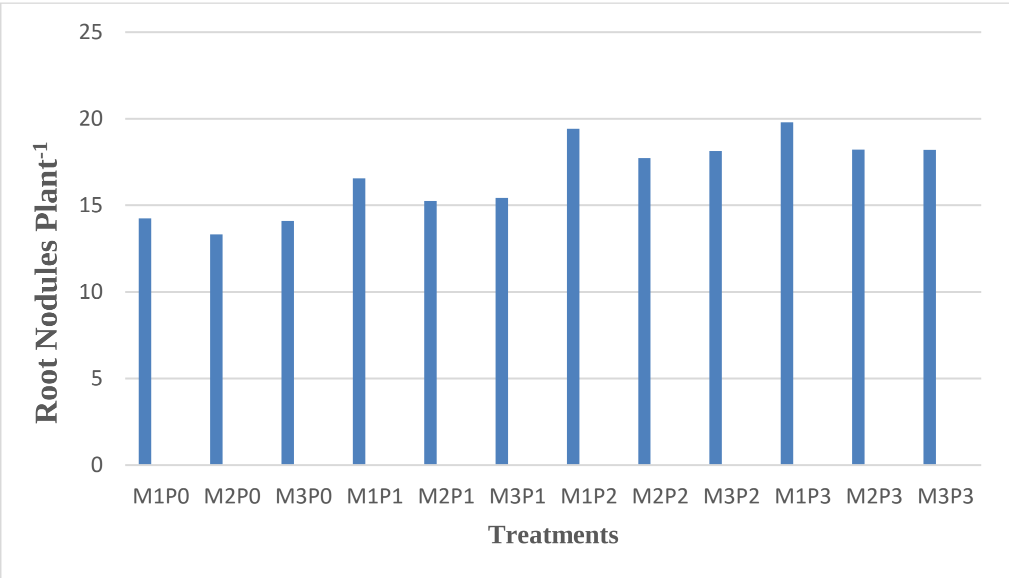

Fig. 3. Effect of phosphate solubilizing microorganisms and phosphorus levels on the number of root nodules per plant of green gram at 45 DAS

Table 7. Effect of phosphorus solubilizing microorganisms and phosphorus levels on straw yield (kg ha^{-1}) of green gram

Treatment	Phosphorus levels
Seed yield (kg ha^{-1})	
Microorganisms (M)	
M_1	1221.95
M_2	1135.65
M_3	1146.94
SE (±)	**13.751**
CD at 5 %	**40.326**
Phosphorus (P)	
P_0	687.68
P_1	1188.02
P_2	1373.08
P_3	1424.27
SE (±)	**15.878**
CD at 5%	**46.564**
M x P	
SE (±)	**27.501**
CD at 5%	**80.652**

Table 8. Interaction of phosphorus solubilizing microorganisms and phosphorus levels on seed yield (kg ha^{-1}) of green gram

	Phosphorus levels				
PSM	**P0**	**P1**	**P2**	**P3**	**MEAN**
Seed Yield (kg/ha)					
M1	690.79	1202.28	1454.48	1540.25	**1221.95**
M2	685.85	1170.92	1328.58	1357.26	**1135.65**
M3	686.42	1190.88	1336.18	1375.31	**1146.94**
Mean	**687.68**	**1188.02**	**1373.08**	**1424.27**	
	M		**P**		**M × P**
SE (±)	**13.751**		**15.878**		**27.501**
CD at 5%	**40.326**		**46.564**		**80.652**

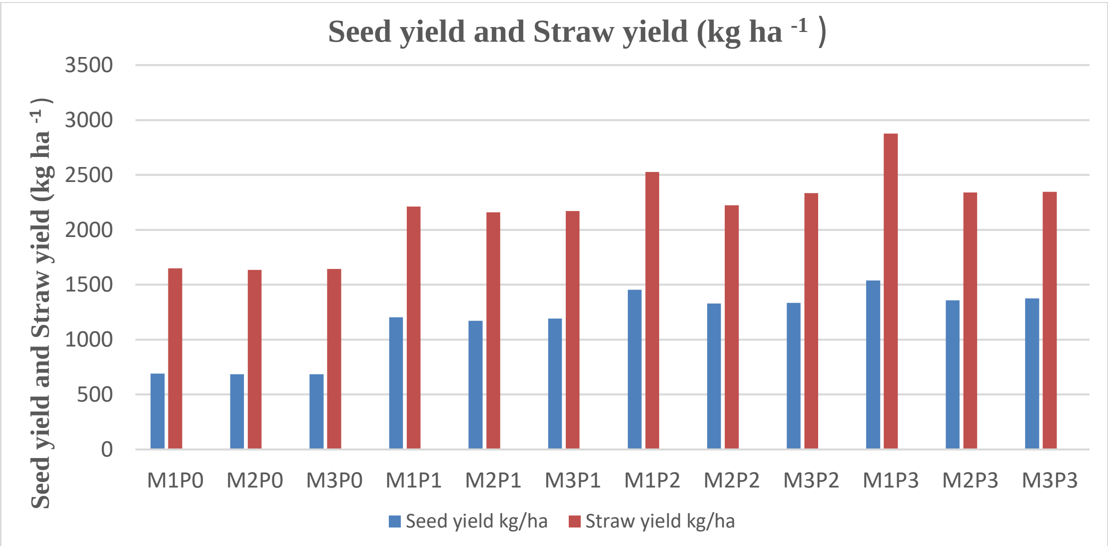

Fig. 4. Effect of phosphate solubilizing microorganisms and phosphorus levels on seed yield (kg ha^{-1}) and straw yield (kg ha^{-1}) of green gram

3.2.2 Straw yield (kg ha^{-1})

Table 9. Effect of phosphorus solubilizing microorganisms and phosphorus levels on straw yield (kg ha^{-1}) of green gram

Treatment	Phosphorus Level
Straw Yield (kg/ha)	
Microorganism (M)	
M_1	2315.92
M_2	2089.49
M_3	2123.62
SE (±)	**29.239**
CD at 5 %	**85.748**
Phosphorus (P)	
P_0	1642.65
P_1	2180.66
P_2	2362.39
P_3	2519.68
SE (±)	**33.763**
CD at 5%	**99.014**
M × P	
SE (±)	**58.479**
CD at 5 %	**171.497**

Table 10. Interaction of phosphorus solubilizing microorganisms and phosphorus levels on straw yield (kg ha^{-1}) of green gram

			Phosphorus levels		
PSM	**P0**	**P1**	**P2**	**P3**	**MEAN**
Straw Yield (kg/ha)					
M_1	1649.19	2211.59	2527.83	2875.10	**2315.92**
M_2	1634.70	2160.11	2224.31	2338.84	**2089.49**
M_3	1644.06	2170.30	2335.04	2345.11	**2123.62**
Mean	**1642.65**	**2180.66**	**2362.39**	**2519.68**	
	M		**P**		**M × P**
SE (±)	**29.239**		**33.763**		**58.479**
CD at 5%	**85.748**		**99.014**		**171.497**

Response of phosphorus solubilizing microorganisms and phosphorus levels on straw yield of green gram tabulated in Tables (9 and 10) and depicted in Fig. 4. It ranges from 1634.70 to 2875.10 kg/ha, respectively.

These results were confirmatory with Kant [13] revealing the effect of biofertilizer and P levels on black gram. Straw yield was significantly increased (31.60q/ha) with the application of 75 kg P_2O_5 ha^{-1} along with PSB+ *Rhizobium* over the control (21.48q/ha). Increased straw yield due to better root growth with increased solubilization which leads to proper nutrient uptake.

Singh's [14] results indicated that the application of 80 kg P_2O_5 ha^{-1} long with PSB significantly increased the straw yield. Increased straw yield by 27.36 q/ha as compared to control (11.25 q/ha) due to dry matter accumulation, increasing translocation due to increasing potassium and phosphorus uptake that results in quick and easy translocation of photosynthate from source to sink.

Venkatarao [14] found that the application of 40 kg P2O5 ha^{-1} along with PSB + *Aspergillus awamori* significantly increased straw yield by 2988 kg/ha and 2867 kg/ha as compared to control (2100 kg ha^{-1} and 2123 kg ha^{-1}`) [15].

4. CONCLUSION

Effect of Phosphate Solubilizing Microorganism and phosphorus levels on growth parameter significantly affected. When application of 125% RDP, combined with *Aspergillus awamori* it resulted in a significant increase in various plant attributes. These included plant height, which reached 61.21 cm, the number of leaves per plant (30.56), the number of nodules per plant (19.80). These improvements were consistently observed across all stages of the crop.

The application of treatment M_1P_1 @ 125% RDP combined with *Aspergillus awamori* resulted in the most favourable yield and yield-related outcomes. This included the highest number of a seed yield of 1540.25 kg/ha, and a straw yield of 2875.10 kg/ha. These results were on par with the outcomes of treatment M_1P_2 @100% RDP combined with *Aspergillus awamori* resulted in seed yield 1454.58 kg/ha, and straw yield 2527.83 kg/ha. In comparison, these treatments surpassed all other approaches. Conversely, the lowest seed yield (685.85 kg/ha) and straw yield (1634.70 kg/ha) were observed with treatment M_2P_0 (control).

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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