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Krishnshankar Tripathi
Research Scholar, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Dr. PK Mishra
Professor, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Smriti Singh
Research Scholar, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Amar Singh
Research Scholar, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Shivani Thakur
Research Scholar, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Dr. Amit Kumar Jha
Assistant Professor, Department of Agronomy, College of Agriculture, Powarkheda, JNKVV, Jabalpur, Madhya Pradesh, India

Corresponding Author:
Krishnshankar Tripathi
Research Scholar, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur, Madhya Pradesh, India

Effect of phosphorus levels and phosphate-solubilizing bacteria on growth and yield of rice (*Oryza sativa* L.)

Krishnshankar Tripathi, PK Mishra, Smriti Singh, Amar Singh, Shivani Thakur and Amit Kumar Jha

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Abstract
The present investigation entitled "Effect of Phosphorus Levels and Phosphate-Solubilizing Bacteria on Growth and Yield of Rice (*Oryza sativa* L.)" was conducted during the *Kharif* season of 2024 at the Agroforestry Research Farm, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur (M.P.). The experiment was laid out in randomized block design with eight treatments and three replications, comprising different phosphorus levels (100%, 75%, and 50% of recommended dose) with or without inoculation of phosphate-solubilizing biofertilizers such as Arbuscular Mycorrhiza (AM) and Phosphate Solubilizing Bacteria (PSB). The rice variety PB-1 (Pusa Basmati-1) was transplanted on June 20, 2024, with a spacing of 20 cm, using a seed rate of 40 kg/ha and recommended fertilizer dose of 120:60:40 NPK kg/ha. Results indicated that plant population at 30 DAT and harvest remained unaffected, showing uniform stand across treatments. Plant height, tiller number and dry matter accumulation increased progressively, with T_1 (100% P), T_6 (75% P + PSB) and T_4 (75% P + AM) consistently recording the highest values, while control (T_8) showed the lowest. Grain and straw yields were significantly influenced, with maximum grain yield (4216 kg ha^{-1}) obtained in T_1, followed by T_6 (4112 kg ha^{-1}) and T_4 (4108 kg ha^{-1}), which were statistically at par. Similarly, straw yield was highest under T_1 (7367 kg ha^{-1}), followed by T_6 (7297 kg ha^{-1}) and T_4 (7260 kg ha^{-1}). Control plots recorded the lowest productivity (2841 and 5585 kg ha^{-1} for grain and straw, respectively). Harvest index showed non-significant variation, ranging from 33.72% to 36.40%.

Keywords: Rice, growth, yield, phosphorus levels, phosphate-solubilizing bacteria

Introduction
Rice (*Oryza sativa* L.), belonging to the Poaceae family, is one of the world's most important cereal crops. It contains about 80.4% carbohydrates, 2.7% protein and 0.3% fat, along with vital micronutrients like vitamin B6, magnesium, calcium and iron. In India, rice holds a prime position as the staple food crop, accounting for nearly one-fourth of the cultivated land and providing around 43% of calorie intake to more than 60% of the population (Verma *et al*., 2023) [16]. Worldwide, rice is cultivated on over 162 million hectares. In India alone, it occupies about 50 million hectares, with an annual production of roughly 145 million tonnes and an average productivity of 4.35 t ha^{-1} (USDA, 2024). In Madhya Pradesh, rice cultivation spans nearly 3.8 million hectares, producing 13.1 million tonnes annually, with an average yield of 3.4 t ha^{-1} (Farmer Welfare and Agriculture Development Department, M.P., 2022-23).

Phosphorus (P) is a crucial macronutrient in rice cultivation, essential for energy transfer, root development, tillering, and grain formation, yet much of the soil phosphorus remains unavailable to plants due to fixation with calcium, iron, and aluminum compounds (Sharma *et al*., 2018) [12]. Overreliance on chemical fertilizers to correct P deficiency not only raises cultivation costs but also leads to environmental concerns such as nutrient leaching and declining soil fertility. To address this, integrated nutrient management has gained significance, where inorganic fertilizers are supplemented with bio-inoculants like phosphate-solubilizing bacteria (PSB). These microbes release organic acids and enzymes that solubilize unavailable phosphorus, thereby improving nutrient uptake, enhancing plant growth, sustaining yields, and simultaneously reducing the dependence on chemical fertilizers (Kumar *et al.,* 2020) [7].

The present study is important because it explores the combined effect of different phosphorus fertilizer levels with PSB inoculation on growth and yield performance of rice. By assessing whether partial substitution of chemical phosphorus with PSB can sustain or enhance productivity, the study contributes to the development of integrated nutrient management strategies.

Materials and Methods

A field experiment entitled "Effect of Phosphorus Levels and Phosphate-Solubilizing Bacteria on Growth and Yield of Rice (*Oryza sativa* L.)" was conducted during the *Kharif* season of 2024 at the Agroforestry Research Farm, Department of Agronomy, JNKVV, Jabalpur (M.P.). The experiment was laid out in a randomized block design with eight treatments and three replications, comprising different phosphorus levels (100%, 75%, and 50% of the recommended dose) with or without inoculation of phosphate-solubilizing inoculants (Arbuscular Mycorrhiza and Phosphate-Solubilizing Bacteria) along with a control. The gross plot size was 5.0 × 4.0 m with a net plot size of 4.0 × 3.6 m, spacing of 20 cm between rows, and distances of 1.0 m and 1.5 m maintained between plots and replications, respectively. Rice variety PB-1 (Pusa Basmati-1) was transplanted on June 20, 2024, at a seed rate of 40 kg ha^{-1}, with recommended fertilizer dose of 120:60:40 N:P:K kg ha^{-1}. The recommended dose of AM and PSB inoculants was applied as basal @ 5 kg ha^{-1}. Standard agronomic practices were followed to raise a healthy crop, and observations on plant population, growth attributes, and yield parameters were recorded at different growth stages and at harvest. Observations on growth and yield attributes of rice were recorded at different crop stages using standard procedures. Plant population per meter row length was counted at five randomly selected spots in each plot at 20 DAT and harvest, averaged, and converted to plants per square meter. Plant height was measured from ground level to the top fully expanded leaf at 30, 60, 90 DAT, and harvest, using five randomly selected plants per plot. The number of tillers per meter row was recorded at the same intervals from five random spots, averaged, and expressed per square meter, while leaves per tiller were counted from five tillers per plot at 30, 60, and 90 DAT to assess vegetative growth. Grain yield was recorded from net plots after winnowing and cleaning, and expressed in kg ha^{-1}, while straw yield was derived by subtracting grain yield from biological yield. The data were statistically analyzed using randomized block design (RBD) with analysis of variance (ANOVA) as per Gomez and Gomez (1984) [6]. Standard error of mean (SEm±) and critical difference (CD) at 5% probability were calculated wherever applicable to test significance of treatment means.

Results and Discussion

The present investigation entitled "Effect of Phosphorus Levels and Phosphate-Solubilizing Bacteria on Growth and Yield of Rice (*Oryza sativa* L.)" was carried out during the *Kharif* season of 2024 at the Agroforestry Research Farm, Department of Agronomy, College of Agriculture, JNKVV, Jabalpur (M.P.). The experiment was laid out in a randomized block design with eight treatments and three replications, consisting of T_1: 100% P, T_2: 75% P, T_3: 50% P, T_4: 75% P + AM (5 kg ha^{-1} as basal), T_5: 50% P + AM (5 kg ha^{-1} as basal), T_6: 75% P + PSB (5 kg ha^{-1} as basal), T_7: 50% P + PSB (5 kg ha^{-1} as basal), and T_8: control (untreated). The rice variety PB-1 (Pusa Basmati-1) was grown under recommended agronomic practices and observations were recorded on growth parameters and yield, along with phosphorus concentration in shoots, roots, grains and straw to evaluate the effect of treatments.

Growth parameters

Plant Population (m^{-2})

The plant population of rice at 30 DAT and at harvest, as influenced by different phosphorus levels and P-solubilizing inoculants, is presented in Table 1 and Figure 1. The data revealed that variations in phosphorus levels and inoculant application did not significantly affect plant population at either stage. At 30 DAT, plant population ranged from 46.33 to 47.33 plants m^{-2}, while at harvest it ranged from 46.00 to 46.67 plants m^{-2}, indicating a uniform crop stand across all treatments. These results are consistent with Meena *et al.* (2017) [11], who found that phosphorus-solubilizing bacteria had no significant effect on the early plant population in rice. In a similar study, Kumar *et al.* (2020) [7] reported minimal variation in rice seedling emergence under different phosphorus levels, which they attributed to consistent seed vigour and favourable environmental conditions.

Plant Height (cm)

Plant height of rice increased progressively from 30 DAT to harvest, with the highest rate of growth observed between 30 and 60 DAT (Table 1, Figure 1). At 30 DAT, the maximum height was recorded under 100% P (T_1, 45.36 cm), 75% P + PSB (T_6, 45.16 cm), and 75% P + AM (T_4, 44.24 cm), while the minimum was observed in control (T_8, 38.48 cm). At 60 DAT, T_1 (78.49 cm), T_6 (77.94 cm), and T_4 (77.32 cm) maintained the tallest plants, and control remained shortest (68.12 cm). At 90 DAT, maximum heights were noted in T_1 (106.37 cm), T_6 (103.18 cm), and T_4 (102.76 cm), with control recording the minimum (81.20 cm). At harvest, the tallest plants were again obtained in T_1 (104.61 cm), T_6 (101.71 cm), and T_4 (100.81 cm), while the shortest plants were in control (T_8), with intermediate heights in 50% P + PSB (T_7) and 50% P + AM (T_5). These results indicate that phosphorus application, particularly in combination with PSB or AM inoculants, consistently enhanced vegetative growth of rice across all growth stages. These results are in agreement with previous studies indicating that phosphorus application markedly increases plant height in rice. Research by Babu *et al.* (2008) [2], Alam *et al.* (2009), Fageria and Oliveira (2010), and Amanullah *et al.* (2016) [1] demonstrated that higher phosphorus levels, alone or combined with bio-inoculants, led to greater plant height, corroborating the observations from the 100% phosphorus and bio-inoculant treatments in the present study.

Tillers (m^{-2})

The number of tillers per square meter increased progressively from 30 DAT to harvest, with the highest rate of increase observed between 30 and 60 DAT (Table 2, Figure 2). At 30 DAT, the maximum tiller count was recorded under 100% P (T_1, 272 m^{-2}), 75% P + PSB (T_6, 266 m^{-2}), and 75% P + AM (T_4, 262 m^{-2}), while the minimum was in control (T_8, 195 m^{-2}). At 60 DAT, T_1 (362 m^{-2}), T_6 (353 m^{-2}), and T_4 (351 m^{-2}) maintained the highest tiller numbers, with intermediate values in 50% P + PSB (T_7, 335 m^{-2}) and 50% P + AM (T_5, 321 m^{-2}), and the lowest in T_3 (299 m^{-2}) and control (328 m^{-2}). At 90 DAT, maximum tillers were observed in T_1 (444 m^{-2}), T_6 (439 m^{-2}), and T_4 (436 m^{-2}), while control remained lowest (376 m^{-2}). At harvest, the trend continued with T_1 (439 m^{-2}), T_6 (435 m^{-2}), and T_4 (431 m^{-2}) recording the highest tiller numbers, intermediate values in T_7 (410 m^{-2}) and T_5 (406 m^{-2}), and the lowest in T_2 (409 m^{-2}), T_3 (390 m^{-2}), and control (370 m^{-2}). These results indicate that phosphorus application, especially in combination with PSB or AM, significantly enhanced tiller production throughout the crop growth period. In a similar investigation, Babu *et al*. (2008) [2] reported that applying 240 kg N ha^{-1} along with 60 kg P_2O_5 ha^{-1} increased productive tillers to 416 m^{-2}. Likewise, Amanullah *et al*. (2016) [1] found that increasing phosphorus levels (0, 30, 60, and 90 kg P ha^{-1}) positively affected the number of tillers per hill, with the maximum observed at 90 kg P ha^{-1}.

Plant Dry Weight (g m^{-2})

Plant dry weight of rice increased progressively from 30 DAT to harvest, with the highest rate of accumulation observed between 30 and 60 DAT (Table 2, Figure 3). At 30 DAT, the highest dry weight was recorded under 75% P + PSB (T_6, 5.73 g m^{-2}), 75% P + AM (T_4, 5.23 g m^{-2}), and 100% P (T_1, 4.86 g m^{-2}), while the minimum was observed in control (T_8, 3.11 g m^{-2}). At 60 DAT, maximum dry weights were observed in T_1 (24.10 g m^{-2}), T_6 (23.67 g m^{-2}), and T_4 (23.27 g m^{-2}), with the lowest in control (15.63 g m^{-2}). At 90 DAT, the tallest plants in terms of biomass were recorded in T_1 (40.58 g m^{-2}), T_6 (39.78 g m^{-2}), and T_4 (39.22 g m^{-2}), while control remained lowest (30.52 g m^{-2}). At harvest, the maximum dry weight continued to be achieved under T_1 (48.50 g m^{-2}), T_6 (47.51 g m^{-2}), and T_4 (47.03 g m^{-2}), with intermediate values in T_2 (45.40 g m^{-2}) and T_5 (44.83 g m^{-2}), and the minimum in T_7 (43.77 g m^{-2}), T_3 (42.02 g m^{-2}), and control (41.25 g m^{-2}). These results indicate that phosphorus application, particularly in combination with PSB or AM inoculants, consistently enhanced biomass accumulation in rice throughout the crop growth period. These results are consistent with the observations of Elekhtyar *et al*. (2022) [4] and Meena *et al*. (2015) [10].

Yield of Rice

Grain Yield (kg ha^{-1})

Grain yield of rice was significantly influenced by different phosphorus levels and P-solubilizing inoculants (Table 3, Figure 4). The highest grain yield was recorded under 100% P (T_1, 4216 kg ha^{-1}), followed closely by 75% P + PSB (T_6, 4112 kg ha^{-1}) and 75% P + AM (T_4, 4108 kg ha^{-1}), which were statistically at par. Moderate yields were obtained with 50% P + AM (T_5, 3895 kg ha^{-1}), 75% P (T_2, 3707 kg ha^{-1}), and 50% P + PSB (T_7, 3702 kg ha^{-1}), all statistically similar, while the lowest yields were recorded under 50% P (T_3, 3577 kg ha^{-1}) and control (T_8, 2841 kg ha^{-1}). These results indicate that phosphorus application, especially in combination with PSB or AM inoculants, significantly enhanced grain production in rice.

Straw Yield (kg ha^{-1})

Straw yield of rice was significantly influenced by different phosphorus levels and P-solubilizing inoculants (Table 3, Figure 4). The highest straw yields were recorded under 100% P (T_1, 7367 kg ha^{-1}), 75% P + PSB (T_6, 7297 kg ha^{-1}), and 75% P + AM (T_4, 7260 kg ha^{-1}), which were statistically at par. Moderate straw yields were observed with 50% P + AM (T_5, 6939 kg ha^{-1}), 75% P (T_2, 6791 kg ha^{-1}), and 50% P + PSB (T_7, 6747 kg ha^{-1}), while the lowest yields were recorded under 50% P (T_3, 6662 kg ha^{-1}) and control (T_8, 5585 kg ha^{-1}). These findings indicate that integrated application of phosphorus with PSB or AM inoculants significantly enhanced straw production in rice.

Harvest Index (%)

Harvest index, which indicates the efficiency of the crop in converting total biomass into economic yield, was not significantly influenced by different phosphorus levels and P-solubilizing inoculants (Table 3, Figure 5). However, numerical variations were observed, with values ranging from 33.72% to 36.40% across the treatments, suggesting a relatively consistent proportion of grain to total biomass irrespective of the applied treatments.

These results are corroborated by Laxminarayana (2005) [9], who reported grain yields of 5.43 t ha^{-1} with 90 kg P_2O_5 ha^{-1} and 5.29 t ha^{-1} with 60 kg P_2O_5 ha^{-1} when combined with VAM. Similarly, Vahed *et al*. (2012) found that applying 50% RDF of phosphorus along with PSB resulted in the highest grain (4407.3 kg ha^{-1}) and straw yields (4133.3 kg ha^{-1}). Singh *et al*. (2017) [13] recorded grain and straw yields of 50.55 and 74.43 q ha^{-1}, respectively, under phosphorus-enriched treatments. Additionally, Chandra and Sharma (2021) [3] demonstrated that inoculation with phosphorus-solubilizing microbes significantly increased grain yield by 65.6%, straw yield by 26.8%, and harvest index by 14.9% in rice.

Table 1: Effect of phosphorus levels and P solubilizing inoculants on Plant population (m^2) and Plant height (cm) of Rice at Different Growth Stages

Treatments	Plant population (m^2)		Plant height (cm)			
	At 20 DAT	At harvest	At 30 DAT	At 60 DAT	At 90 DAT	At harvest
T1: 100% P	47.00	46.33	45.36	78.49	106.37	104.61
T_2: 75% P	47.33	46.67	43.20	75.11	97.52	97.32
T_3: 50% P	47.00	46.33	41.43	72.74	92.68	92.20
T_4: 75% P + AM @ 5 kg/ha as basal	47.33	46.67	44.24	77.32	102.76	100.81
T_5: 50% P + AM @ 5 kg/ha as basal	47.00	46.33	43.52	75.41	96.72	96.12
T_6: 75% P + PSB @ 5 kg/ha as basal	47.33	46.67	45.16	77.94	103.18	101.71
T_7: 50% P + PSB @ 5 kg/ha as basal	47.00	46.33	43.97	76.90	98.11	97.92
T_8: Control	46.33	46.00	38.48	68.12	81.20	87.11
SEm±	0.54	0.58	0.56	0.64	1.20	1.30
CD (p=0.05)	NS	NS	1.72	1.95	3.66	4.00

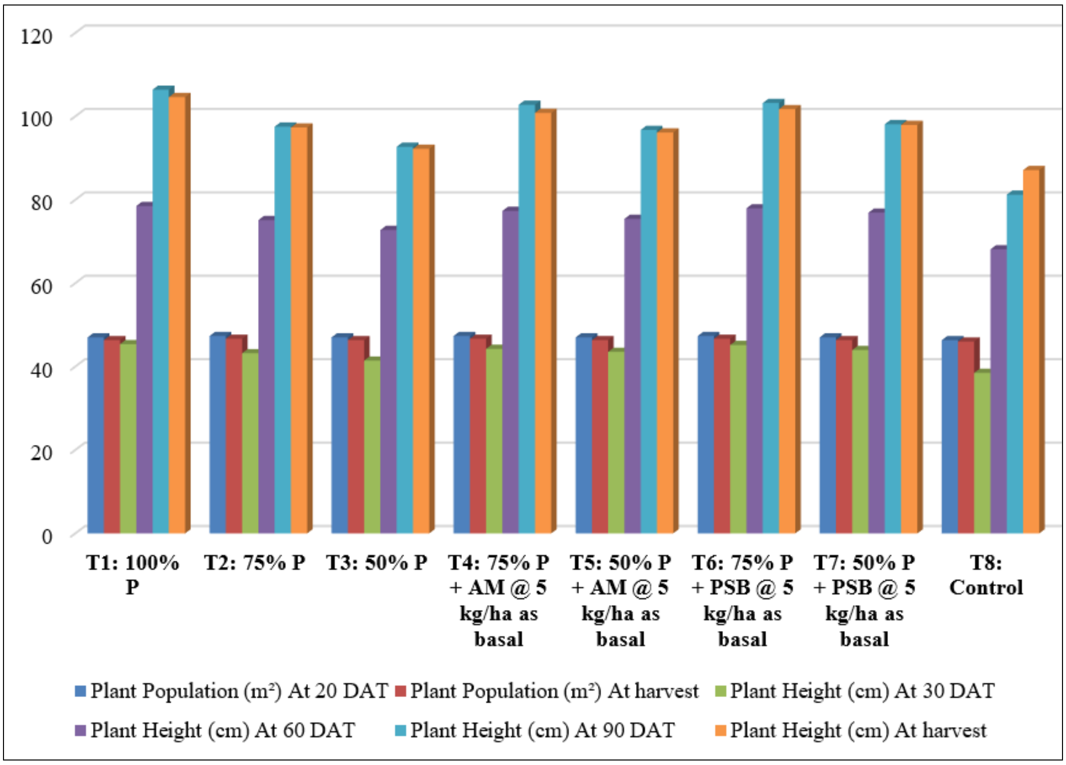

Fig 1: Effect of phosphorus levels and P solubilizing inoculants on Plant population (m²) and Plant height (cm) of Rice at Different Growth Stages

Table 2: Effect of phosphorus levels and P solubilizing inoculants on Tillers and Plant dry weight of Rice at Different Growth Stages

Treatments	Tillers (m²)				Plant Dry Weight (g m²)			
	At 30 DAT	At 60 DAT	At 90 DAT	At harvest	At 30 DAT	At 60 DAT	At 90 DAT	At harvest
T1: 100% P	272	362	444	439	5.73	24.10	40.58	48.50
T_2: 75% P	242	328	418	409	4.50	20.20	36.40	45.40
T_3: 50% P	224	299	395	390	3.20	16.48	32.32	42.02
T_4: 75% P + AM @ 5 kg/ha as basal	262	351	436	431	5.43	23.27	39.22	47.03
T_5: 50% P + AM @ 5 kg/ha as basal	234	321	410	406	4.03	19.55	35.87	44.83
T_6: 75% P + PSB @ 5 kg/ha as basal	266	353	439	435	5.56	23.67	39.78	47.51
T_7: 50% P + PSB @ 5 kg/ha as basal	236	335	413	410	3.55	18.26	34.76	43.77
T_8: Control	195	268	376	370	3.11	15.63	30.52	41.25
SEm±	4.48	4.73	3.09	3.44	0.11	0.29	0.41	0.58
CD (p=0.05)	13.72	14.49	9.47	10.54	0.36	0.90	1.25	1.78

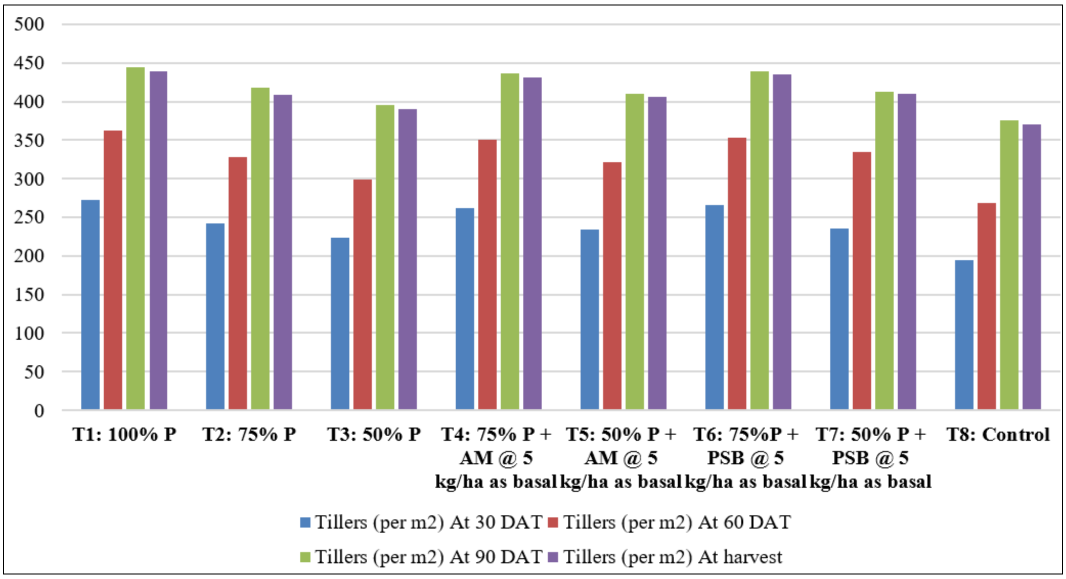

Fig 2: Effect of phosphorus levels and P solubilizing inoculants on Tillers at various intervals of crop growth

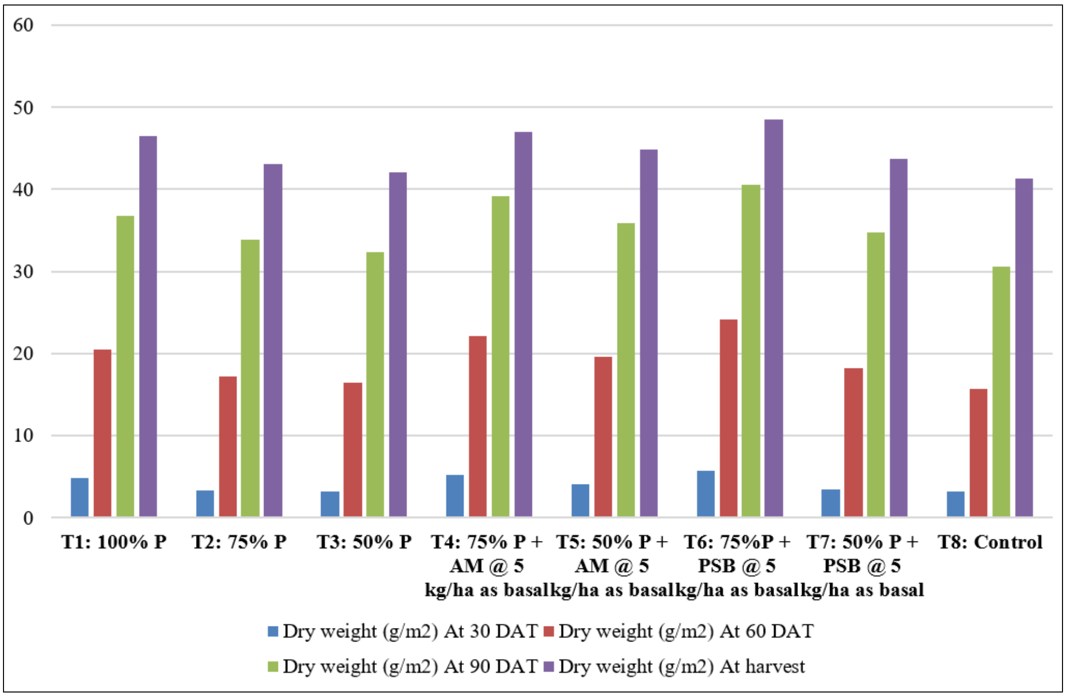

Fig 3: Effect of phosphorus levels and P solubilizing inoculants on Plant dry weight at different intervals and harvest of crop

Table 3: Effect of phosphorus levels and P solubilizing inoculants on Grain, Straw yield and Harvest index of Rice

Treatments	Grain Yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index (%)
T1: 100% P	4216	7367	36.40
T_2: 75% P	3707	6791	35.31
T_3: 50% P	3577	6662	34.93
T_4: 75% P + AM @ 5 kg/ha as basal	4108	7260	36.07
T_5: 50% P + AM @ 5 kg/ha as basal	3895	6939	35.95
T_6: 75% P + PSB @ 5 kg/ha as basal	4112	7297	36.04
T_7: 50% P + PSB @ 5 kg/ha as basal	3702	6747	35.43
T_8: Control	2841	5585	33.72
SEm±	38.44	36.61	-
CD (p=0.05)	117.79	112.18	-

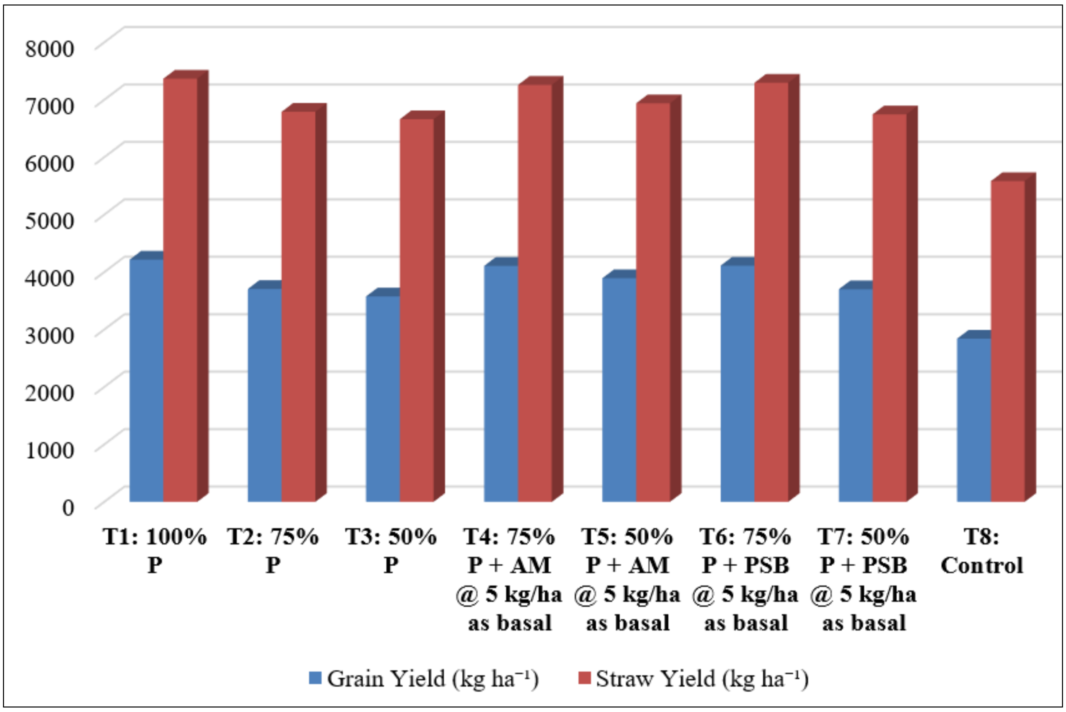

Fig 4: Effect of phosphorus levels and P solubilizing inoculants on Grain and straw yield

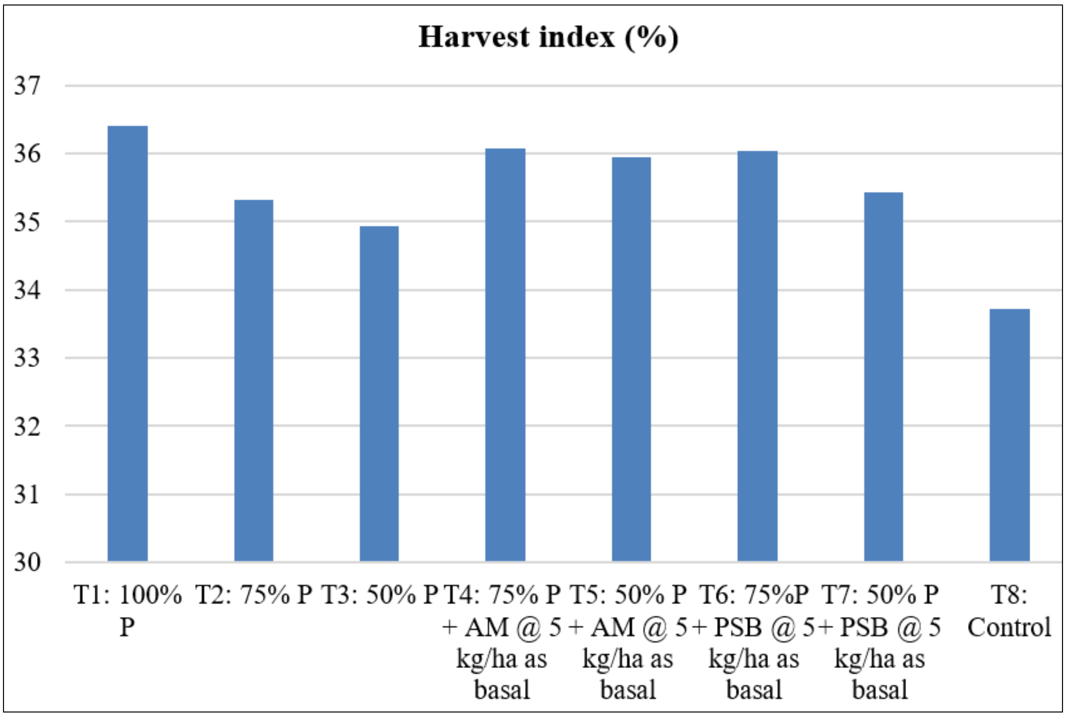

Fig 5: Effect of phosphorus levels and P solubilizing inoculants on harvest index

Conclusion

The results revealed that plant population and harvest index were not significantly affected by phosphorus levels and P-solubilizing inoculants, with plant stand remaining uniform from 46.33–47.33 plants m^{-2} at 30 DAT and 46.00–46.67 plants m^{-2} at harvest, and harvest index values ranging from 33.72% to 36.40%. However, significant improvements were observed in growth and yield attributes. Treatments T_1 (100% P), T_6 (75% P + PSB), and T_4 (75% P + AM) consistently recorded the highest plant height, tiller number, and dry matter production, while the control (T_8) remained lowest throughout. Grain yield was maximum in T_1 (4216 kg ha^{-1}), followed by T_6 (4112 kg ha^{-1}) and T_4 (4108 kg ha^{-1}), with corresponding straw yields of 7367, 7297, and 7260 kg ha^{-1}, respectively, compared to the lowest yields in the control (2841 kg ha^{-1} grain and 5585 kg ha^{-1} straw).

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