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P Dhanush

Department of Agronomy,
Acharya N. G. Ranga Agricultural
University, Agricultural College,
Bapatla, Andhra Pradesh, India

M Srinivas

Department of Agronomy,
Acharya N. G. Ranga Agricultural
University, Agricultural College,
Bapatla, Andhra Pradesh, India

K Anny Mrudhula

Department of Agronomy,
Acharya N. G. Ranga Agricultural
University, Agricultural College,
Bapatla, Andhra Pradesh, India

P Madhu Vani

Department of Agronomy,
Acharya N. G. Ranga Agricultural
University, Agricultural College,
Bapatla, Andhra Pradesh, India

Corresponding Author:

P Dhanush

Department of Agronomy,
Acharya N. G. Ranga Agricultural
University, Agricultural College,
Bapatla, Andhra Pradesh, India

Effect of integrated phosphorus management on yield and biochemical activities in rice under saline conditions

P Dhanush, M Srinivas, K Anny Mrudhula and P Madhu Vani

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Abstract

A field experiment was carried out on clay soils during *kharif*, 2025-2026 at OFT Farm, Saline Water Scheme, Bapatla to assess the Effect of Integrated phosphorus management in *kharif* Rice (*Oryza sativa* L.) under saline conditions. The experiment was laid out in a randomized block design with nine treatments in three replications. The results of the investigation revealed that grain (5140 kg ha^{-1}) and straw yield (5383 kg ha^{-1}), total chlorophyll content (2.8 mg g^{-1}) were significantly higher with application of 100% RDP+PSB+VAM, whereas biochemical activity such as, proline content ($34 \mu\text{g g}^{-1}$), total phenolic content ($53 \text{ mg}/100 \text{ g}$), peroxidase activity ($6.24 \text{ min}^{-1}\text{g}^{-1}$), Na^+/K^+ ratio (0.68) acid ($45.4 \mu\text{g pNP g}^{-1} \text{ hr}^{-1}$) and alkaline ($37.2 \mu\text{g pNP g}^{-1} \text{ hr}^{-1}$) phosphatase activity were found significantly higher with control treatment.

Keywords: Proline, peroxidase, phenolic content, chlorophyll, phosphatase

Introduction

Rice (*Oryza sativa*) is one of the most important staple foods in the world, serving as a primary source of nourishment for over half of the global population. It is estimated that rice provides approximately 20% of the world's caloric intake, underscoring its importance in global food security and agricultural economy. Salinity is a major soil and water-related constraint in coastal areas, severely affecting agricultural productivity and ecological stability. It is the major abiotic stress limiting rice productivity as it adversely affects soil properties, nutrient availability and absorption by the plant. Salinity further impairs photosynthesis through stomatal closure, chlorophyll degradation drastically reducing carbohydrate production and biomass accumulation Mrudhula *et al.* (2025)^[9]. At the cellular level, overproduction of reactive oxygen species (ROS) causes oxidative damage to membranes, proteins, and DNA, overwhelming the plant's natural antioxidant defences.

To overcome the limitations of salinity, biofertilizers were applied in combination with inorganic fertilizers to improve the soil rhizosphere activity and thereby improving the nutrient uptake by plants under salt stress conditions.

Materials and Methods

A field experiment was conducted at OFT farm, Saline Water Scheme Bapatla, Andhra Pradesh during *kharif*, 2025. The soil of the experimental field was clay in texture, neutral in reaction with pH 7.52, electrical conductivity 6.4 dS m^{-1} , saline, medium in organic carbon, low in available nitrogen, medium in available phosphorus and medium in available potassium. Average mean maximum temperature was 32.0°C and minimum temperature was 22.0°C during the crop growth period. The total amount of rainfall received was 903.9 mm with 31 rainy days. The experiment was laid out in Randomized Block Design with 9 treatments replicated thrice. The treatments include, T₁: Control (no P); T₂: 100% RDP ($60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$); T₃: 100% RDP + PSB; T₄: 100% RDP + VAM; T₅: 100% RDP + PSB + VAM; T₆: 75% RDP; T₇: 75% RDP + PSB; T₈: 75% RDP + VAM; and T₉: 75% RDP + PSB + VAM. Nutrient NPK was applied in the form of urea, Single Super Phosphate (SSP) and Muriate of Potash (MOP) respectively. Nitrogen was applied in three equal splits *i.e.*, as basal, 30 DAT and 60 DAT and entire dose of phosphorus was applied as basal, for treatments receiving 100% RDP, $60 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ was applied, while for treatments receiving 75% RDP, $45 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ was applied. In case of biofertilizers *i.e.* PSB (Phosphate solubilizing

bacteria), and VAM (vesicular arbuscular mycorrhizae) were thoroughly mixed with vermicompost and applied in experimental plots as per the treatments. Potassium was applied in two splits at *i.e.* basal and at 30 DAT. Gap filling, weeding, irrigation and other necessary intercultural operations were done in proper time. Harvesting was done plot wise, five hills were selected randomly from each unit plot for taking yield component data at harvest. One m² area from each plot was selected from the central portion and was cut manually from the ground level to take grain and straw yields. The harvested crop of each plot was separately bundled, properly tagged and then brought to the threshing floor. The harvested crops were threshed manually. The grain was cleaned and dried to a moisture content of 14 per cent. Straws were sun dried properly. Data recorded for yield parameters were compiled and tabulated in proper form for statistical analysis (Gomez and Gomez 1984)^[4]. Total chlorophyll content in leaves was estimated colorimetrically by dimethyl sulphoxide (DMSO) method as described by Hiscox and Israelstam, (1979)^[6]. The proline content was estimated by following the method of Bates *et al.* (1973)^[1]. The peroxidase content is estimated by following the method of Malik and Singh *et al.*, (1980)^[7]. The phenols content is estimated by following the method of Malik and Singh (1980)^[7]. The method used for Na⁺/K⁺ determination is by flame photometry given by Tandon (1993)^[19].

Results and Discussion

Grain Yield (kg ha⁻¹)

Grain yield of rice was significantly influenced by different phosphorus levels. Significantly the highest grain yield (5140 kg ha⁻¹) was obtained with (T₅) 100% RDP + PSB + VAM highlighting the effectiveness of nutrient application along with biofertilizers in realizing higher productivity. This treatment was statistically at par with (T₃) 100% RDP + PSB (4947 kg ha⁻¹), (T₄) 100% RDP + VAM (4917 kg ha⁻¹), (T₉) 75% RDP+ PSB+ VAM (4900 kg ha⁻¹) (T₇) 75% RDP+ PSB (4783 kg ha⁻¹) and (T₈) 75% RDP + VAM (4753 kg ha⁻¹). Significantly lowest grain yield (3617 kg ha⁻¹) was recorded with (T₁) control treatment. Pratibha Rawat *et al.* (2020)^[12] revealed that these assimilates were subsequently translocated to the developing grains, resulting in improved grain filling and higher yield. Furthermore, sufficient nutrient supply during the early growth stages supports better plant growth and development, which ultimately contributes to increased productivity. Similar findings have been reported by Gudarankaiah *et al.* (2021)^[5], Tejaswini *et al.* (2017)^[20], Bhavani *et al.* (2013)^[2] and Verma *et al.* (2017)^[23].

Straw Yield (kg ha⁻¹)

Straw yield recorded at harvest in different treatments of rice were found comparable with each other and significant difference was observed in straw yield tested under study. Significantly the highest straw yield (5383 kg ha⁻¹) was obtained with (T₅) 100% RDP + PSB + VAM this treatment was statistically at par with (T₃) 100% RDP + PSB (5150 kg ha⁻¹), (T₄) 100% RDP + VAM (5033 kg ha⁻¹), (T₉) 75% RDP+ PSB+ VAM (4917 kg ha⁻¹) (T₇) 75% RDP+ PSB (4900 kg ha⁻¹) and (T₈) 75% RDP + VAM (4833 kg ha⁻¹). Significantly lowest straw yield (4400 kg ha⁻¹) was recorded with (T₁) control treatment. The increased straw yield may be attributed to the synergistic effect of phosphorus fertilization along with PSB and VAM, which enhanced phosphorus availability and uptake, leading to improved root growth, nutrient absorption, and vegetative development. Prasanthnaik *et al.* (2020)^[11] reported that enhanced phosphorus nutrition promotes cell division and photosynthetic efficiency resulting in greater dry matter production and straw yield.

Total chlorophyll content at flowering and maturity

The total chlorophyll content at flowering and maturity were significantly influenced by the application of different levels of phosphorus and biofertilizers tested under study. At flowering, significantly the highest total chlorophyll content (2.8 mg g⁻¹) was recorded in the treatment 100% RDP+PSB+VAM, which was at par with (T₃) 100% RDP+PSB whereas, significantly the lowest total chlorophyll content (1.7 mg g⁻¹) was recorded at control treatment. Rajasekaran *et al.* (2015)^[13] reported that phosphorus plays a vital role in energy transfer, photosynthesis, and chlorophyll synthesis. PSB enhances the solubilization of fixed phosphorus, while VAM improves nutrient and water absorption through an extensive hyphal network.

At maturity, significantly the highest total chlorophyll content (2.2 mg g⁻¹) was observed in the treatment (T₅)100% RDP+PSB+VAM and it was found to be at par with (T₃) 100%RDP +PSB (2.2 mg g⁻¹) and (T₄) 100% RDP +VAM (2.1 mg g⁻¹) treatments. The lowest total chlorophyll content (1.6 mg g⁻¹) was recorded at control treatment, respectively. Shanaz Parvin *et al.* (2020)^[10] reported that the higher chlorophyll content in treatments with biofertilizers indicate delayed senescence and sustained photosynthetic activity owing to better phosphorus nutrition and improved plant health under saline conditions.

Proline content at flowering and maturity

Proline content at harvest and flowering were significantly influenced by the different levels of phosphorus and biofertilizers tested under study. At flowering, significantly the highest proline content (26 µg g⁻¹) was recorded in the treatment (T₁) control, which was at par with (T₂) 100% RDP (24 µg g⁻¹) and (T₆) 75% RDP (25 µg g⁻¹), whereas, significantly the lowest proline content (12 µg g⁻¹) was recorded in the (T₅)100% RDP+PSB+VAM treatment. Shi *et al.* (2007)^[16] revealed that increased accumulation of proline in the control treatment indicates greater stress perception and cellular damage due to nutrient deficiency and salt stress. In contrast, the lower proline content in treatments inoculated with PSB and VAM suggests that these biofertilizers improved phosphorus availability, nutrient uptake, water relations, and ionic balance, thereby reducing stress intensity and the need for osmotic adjustment through proline accumulation. Significantly the highest proline content (34 µg g⁻¹) at maturity was recorded in the treatment (T₁) control, same as at flowering which was at par with (T₂) and (T₆), whereas, significantly the lowest proline content (12 µg g⁻¹) was recorded in the (T₅) treatment. (15 µg g⁻¹). Higher proline content was observed at maturity than at flowering. Under, salt and drought stress conditions, large accumulation of intracellular soluble sugar and proline improves the cell sap concentration, maintains normal cell turgor, prevents excessive water loss and enhances the resistance of plants as reported by Stewart and Lee (1974)^[18].

Total phenols at flowering and maturity

The total phenolic content in rice at flowering and maturity were significantly influenced by the different phosphorus levels and biofertilizers tested under the study. At flowering, significantly the highest phenolic content (42 mg/100 g) was recorded in the treatment (T₁) control, which was at par with (T₆) 75% RDP (38 mg/100 g), whereas, significantly the lowest phenolic content (27 mg/100 g) was recorded in the (T₅)100% RDP+PSB+VAM treatment. Sharma *et al.* (2009)^[15] reported that phenolic compounds are important secondary metabolites that accumulate in plants under stress conditions and play a crucial role in protecting cells against oxidative damage caused by reactive

oxygen species (ROS) Mrudhula *et al.*, (2025) [8]. The higher phenolic content in the control treatment indicates greater oxidative stress induced by salinity and inadequate nutrient availability.

At maturity, significantly the highest phenolic content (53 mg/100 g) was recorded in the treatment (T₁) control, which was at par with (T₆) 75% RDP (49 mg/100 g) and (T₂) 100% RDP (47 mg/100 g) whereas, significantly the lowest phenolic content (29 mg/100 g) was recorded in the (T₅)100% RDP+PSB+VAM treatment. Higher phenolic content was observed at maturity than at flowering. The higher phenolic content at maturity compared to flowering may be attributed to prolonged exposure to salinity stress and age-related physiological changes that enhance the synthesis and accumulation of phenolic compounds as reported by Kumar *et al.*

Peroxidase activity at flowering and maturity

The peroxidase activity in soil was significantly influenced by the different phosphorus levels and biofertilizers tested under the study. At flowering, significantly the highest peroxidase activity (4.96 min⁻¹g⁻¹) was recorded in the treatment (T₁) control, which was at par with (T₆) 75% RDP (4.48 min⁻¹g⁻¹) and (T₂) 100% RDP (3.97 min⁻¹g⁻¹) whereas, significantly the lowest peroxidase activity (1.72 min⁻¹g⁻¹) was recorded in the (T₅)100% RDP+PSB+VAM treatment. Velazahan *et al.* (2006) [22] revealed that under saline conditions, excessive production of reactive oxygen species (ROS) induces higher peroxidase activity as a protective mechanism to detoxify harmful free radicals. Therefore, the elevated peroxidase activity observed in the control treatment which indicates greater oxidative damage and stress.

Significantly the highest peroxidase activity (6.24 min⁻¹g⁻¹) was recorded at maturity in the treatment (T₁) control, which was at par with (T₆) 75% RDP (5.91 min⁻¹g⁻¹), (T₂) 100% RDP (5.32 min⁻¹g⁻¹) and (T₇) 75% RDP+ PSB (5.91 min⁻¹g⁻¹) whereas, significantly the lowest peroxidase activity (2.32 min⁻¹g⁻¹) was recorded in the (T₅)100% RDP+PSB+VAM treatment. Sharma *et al.* (2012) [14] reported that the increase in peroxidase activity at maturity compared to flowering may be attributed to prolonged exposure to salinity stress and enhanced oxidative stress during the later stages of crop growth.

Na⁺ /K⁺ ratio at flowering and maturity

The Na⁺/K⁺ ratio in rice was significantly influenced by different phosphorus levels and biofertilizers tested under study. At flowering significantly the highest Na⁺ /K⁺ ratio (0.54) was recorded in the control treatment, which was at par with (T₆) 75% RDP(0.49), (T₂) 100% RDP (0.46), (T₈) 75% RDP+ VAM (0.41) and (T₇) 75% RDP +PSB (0.37) whereas, the lowest Na⁺ /K⁺

ratio (0.21) was recorded in the treatment (T₅) 100% RDP+PSB+VAM. Mamta *et al.* (2008) [8] reported that at flowering stage, a low Na⁺/K⁺ ratio helps maintain reproductive development, pollen viability, spikelet fertility, and photosynthetic efficiency, thereby reducing yield losses caused by salinity.

At maturity stage significantly the highest Na⁺ /K⁺ ratio (0.68) was recorded in the control treatment, which was at par with (T₆) 75% RDP(0.61), (T₂) 100% RDP (0.56) and (T₈) 75% RDP+ VAM (0.49). The significantly lowest value was recorded by the treatment (T₅) 100% RDP+PSB+VAM (0.32). Tester and Davenport (2003) [21] revealed that at maturity stage, maintaining a favorable Na⁺/K⁺ ratio supports efficient grain filling, nutrient balance, and overall plant health under prolonged salt stress.

Acid phosphatase enzyme activity

The acid phosphatase activity in soil at harvest was significantly influenced by the different phosphorus levels and biofertilizers tested under the study. At harvest, the acid phosphatase activity in soil recorded significantly the highest (45.4 µg pNP g⁻¹ hr⁻¹) in the treatment (T₅) 100% RDP+PSB+VAM, which was at par with (T₃) 100% RDP+PSB (42.7 µg pNP g⁻¹ hr⁻¹), (T₄) 100% RDP+VAM (39.2 µg pNP g⁻¹ hr⁻¹) and (T₉) 75% RDP+PSB+VAM (37.4 µg pNP g⁻¹ hr⁻¹) whereas, significantly the lowest acid phosphatase activity (17.2 µg pNP g⁻¹ hr⁻¹) was recorded at control treatment. Srilatha *et al.* (2013) [17] reported that the increased acid phosphatase activity in treatments inoculated with PSB and VAM may be attributed to enhanced microbial activity and greater root exudation in the rhizosphere.

Alkaline phosphatase enzyme activity

Alkaline phosphatase activity in soil at harvest shown significant difference among the different levels of phosphorus and biofertilizers tested under the study. At harvest, the alkaline phosphatase activity in soil recorded significantly the highest (37.2 µg pNP g⁻¹ hr⁻¹) in the treatment (T₅) 100% RDP+PSB+VAM, which was at par with (T₃) 100% RDP+PSB (34.3 µg pNP g⁻¹ hr⁻¹), (T₄) 100% RDP+VAM (31.4 µg pNP g⁻¹ hr⁻¹), (T₉) 75% RDP+PSB+VAM (29.4 µg pNP g⁻¹ hr⁻¹) and (T₇) 75% RDP+PSB (26.3 µg pNP g⁻¹ hr⁻¹) whereas, significantly the lowest alkaline phosphatase activity (12.2 µg pNP g⁻¹ hr⁻¹) was recorded at control treatment. Ghosh *et al.* (2023) [3] revealed that the enhanced alkaline phosphatase activity in PSB and VAM treated plots may be attributed to increased microbial population, greater root proliferation, and higher secretion of phosphatase enzymes in the rhizosphere.

Table 1: Influence of inorganic nutrients and biofertilizers on grain and straw yield and total chlorophyll content in rice under saline conditions

Treatments	Grain Yield (kg ha ⁻¹)	Straw Yield (kg ha ⁻¹)	Total Chlorophyll content (mg g ⁻¹)	
			At Flowering	At Maturity
T ₁ - Control	3617	4400	1.7	26
T ₂ - RDP (60 kg P ₂ O ₅ ha ⁻¹)	4383	4717	1.8	24
T ₃ - 100% RDP + PSB	4947	5150	2.5	14
T ₄ - 100% RDP + VAM	4917	5033	2.4	17
T ₅ - 100% RDP + PSB + VAM	5140	5383	2.8	12
T ₆ - 75% RDP	4350	4553	1.8	25
T ₇ - 75% RDP + PSB	4783	4900	2.0	19
T ₈ - 75% RDP + VAM	4753	4833	1.9	22
T ₉ - 75% RDP + PSB+VAM	4900	4917	2.2	18
S Em±	252.0	185.8	0.07	1.06
CD (P=0.05)	755.6	557.1	0.21	3.2
CV%	9.4	8.6	5.5	6.9

Table 2: Influence of inorganic nutrients and biofertilizers on proline and total phenolic content in rice under saline conditions

Treatments	Proline content ($\mu\text{g g}^{-1}$)		Total phenolic content (mg/ 100 g)	
	At Flowering	At Maturity	At Flowering	At Maturity
T ₁ - Control	26	34	42	53
T ₂ - RDP (60 kg P ₂ O ₅ ha ⁻¹)	24	30	35	47
T ₃ - 100% RDP + PSB	14	17	28	31
T ₄ - 100% RDP + VAM	17	19	29	33
T ₅ - 100% RDP + PSB + VAM	12	15	27	29
T ₆ - 75% RDP	25	31	38	49
T ₇ - 75% RDP + PSB	19	27	31	40
T ₈ - 75% RDP + VAM	22	28	33	44
T ₉ - 75% RDP + PSB + VAM	18	22	30	36
S Em $\pm$	1.06	1.16	1.5	2.2
CD (P=0.05)	3.2	3.5	4.5	6.6
CV%	6.9	6.0	7.9	8.9

Table 3: Influence of inorganic nutrients and biofertilizers on proline and total phenolic content in rice under saline conditions

Treatments	Peroxidase activity ($\text{min}^{-1} \text{g}^{-1}$)		Na ⁺ /K ⁺ ratio	
	At Flowering	At Maturity	At Flowering	At Maturity
T ₁ - Control	4.96	6.24	0.54	0.68
T ₂ - RDP (60 kg P ₂ O ₅ ha ⁻¹)	3.97	5.32	0.46	0.56
T ₃ - 100% RDP + PSB	1.89	2.48	0.24	0.36
T ₄ - 100% RDP + VAM	1.94	2.96	0.29	0.39
T ₅ - 100% RDP + PSB + VAM	1.72	2.32	0.21	0.32
T ₆ - 75% RDP	4.48	5.91	0.49	0.61
T ₇ - 75% RDP + PSB	2.89	3.96	0.37	0.45
T ₈ - 75% RDP + VAM	3.46	4.23	0.41	0.49
T ₉ - 75% RDP + PSB + VAM	2.31	3.45	0.32	0.41
S Em $\pm$	0.42	0.82	0.06	0.07
CD (P=0.05)	1.3	2.5	0.2	0.2
CV%	5.7	5.8	6.3	7.6

Table 4: Influence of inorganic nutrients and biofertilizers on acid and alkaline phosphatase activity in rice under saline conditions

Treatments	Phosphatase activity ($\mu\text{g pNP g}^{-1} \text{hr}^{-1}$)	
	Acid Phosphatase	Alkaline Phosphatase
T ₁ - Control	17.2	12.2
T ₂ - RDP (60 kg P ₂ O ₅ ha ⁻¹)	21.3	15.7
T ₃ - 100% RDP + PSB	42.7	34.3
T ₄ - 100% RDP + VAM	39.2	31.4
T ₅ - 100% RDP + PSB + VAM	45.4	37.2
T ₆ - 75% RDP	20.3	21.6
T ₇ - 75% RDP + PSB	36.6	26.3
T ₈ - 75% RDP + VAM	34.8	23.8
T ₉ - 75% RDP + PSB + VAM	37.4	29.4
S Em $\pm$	2.69	3.97
CD (P=0.05)	8.1	11.9
CV%	7.1	8.2

Conclusion

Based on the findings, it can be concluded that application of inorganic nutrients along with biofertilizers had significantly improved the yield and reduced the adverse effects of salinity stress in T₅ (100% RDP+PSB+VAM) followed by T₃ (100% RDP+PSB) and T₄ (100% RDP+VAM) thereby, improving the nutrient uptake and soil microbial activity. The application of inorganic nutrients alone in the control treatment showed increased biochemical activity which indicates the plants response towards the salt stress to improve crop growth and productivity.

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