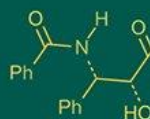


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Effect of phosphorus levels and rice genotypes on grain and straw yield of rice grown in high-phosphorus soil

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Abstract

A field experiment was conducted to evaluate the response of four rice genotypes to different levels of phosphorus (P) application in high phosphorus soil, and to examine the grain yield, straw yield and soil nutrient status relative to the initial (pre-sowing) baseline. The treatments comprised five phosphorus levels i.e., - M1: control, M2: 50%, M3: 100%, M4: 150% and M5: 200% of the recommended dose of phosphorus (RDP) - as Factor A, and four rice genotypes, namely DRR Dhan-78 (S1), WGL-1487 (S2), KNM-1638 (S3) and KPS-2874 (S4), as Factor B, arranged in a Strip Plot Design and 3 replications. The initial soil tested high in available phosphorus (90.2 kg P₂O₅ ha⁻¹) and potassium (287.3 kg K₂O ha⁻¹), low in available nitrogen (153.7 kg N ha⁻¹), and deficient in available zinc (0.431 mg kg⁻¹). Grain yield, straw yield at harvest, and post-harvest available N, K, P, and Zn in the soil were recorded and subjected to statistical analysis. Phosphorus level, genotype, and their interaction had a significant effect on grain and straw yields. Rather than increasing progressively with P dose, yield followed a distinct optimum-and-decline pattern: application of only 50% of the recommended dose (M2) produced the significantly highest grain yield (6784 kg ha⁻¹) and straw yield (8817 kg ha⁻¹), after which yield declined from the recommended dose (M3) to the 150% and 200% doses (M4 and M5), even though all fertilized treatments outyielded the unfertilized control (M1). Among genotypes, DRR Dhan-78 was consistently superior, recording the highest grain (5594 kg ha⁻¹) and straw (7272 kg ha⁻¹) yield, and its combination with 50% RDP gave the single highest grain (7309 kg ha⁻¹) and straw (9497 kg ha⁻¹) yield recorded in the trial. Comparison of post-harvest soil fertility with the initial soil status showed that available nitrogen and potassium were higher under 50% RDP, whereas greater depletion occurred in the control and at higher phosphorus levels, corresponding to lower crop yields. Soil available zinc declined under all treatments, with the greatest reduction at 200% RDP, indicating enhanced phosphorus-induced zinc deficiency under excessive phosphorus application.

Keywords: Rice, phosphorus levels, genotypes, grain yield, straw yield, high-P soil, interaction effect

1. Introduction

Phosphorus (P) is the most important yet most poorly managed nutrient in rice (*Oryza sativa* L.) production. It is indispensable for energy transfer, root proliferation, tillering and grain filling, yet the crop recovers only a modest fraction of applied P in the season of application, since P is fixed as insoluble aluminum, iron and calcium phosphates in most soil types (Brady and Weil, 2017) [1]. To guard against this low recovery, phosphatic fertilizers are frequently applied at or above the recommended dose, irrespective of the phosphorus already present in the soil, and repeated applications over successive seasons lead to a steady accumulation of residual, plant-available phosphorus.

Where such accumulation has raised the native phosphorus status of a soil to a high level, the recommended dose may no longer represent the agronomically or economically optimum rate. Surplus available phosphorus in the rhizosphere can restrict the uptake of micronutrients such as zinc and iron, alter root growth and, beyond a threshold specific to the soil and crop, depress yield rather than enhance it, in addition to raising fertilizer cost and the risk of phosphorus loss to surface water. Rice genotypes further differ appreciably in root architecture, phosphatase activity and internal phosphorus-use efficiency, so that the yield response to a given soil phosphorus status is not uniform across cultivars (Fageria and Baligar, 1997; Rose *et al.*, 2010) [3, 8].

Genotypes capable of sustaining high yield at a reduced phosphorus dose therefore offer a direct route to improving phosphorus-use efficiency without additional fertilizer cost (Vellaikumar and Malarvizhi, 2017) [9].

Despite this, most phosphorus fertilizer trials continue to be conducted on soils of low to medium native fertility, and comparatively little information exists on how modern high-yielding rice genotypes respond to graded phosphorus doses when grown on soils that are already high in available phosphorus. Clarifying this response is essential both to avoid wasteful over-fertilization and to identify genotypes suited to such soils. The present investigation was accordingly undertaken with the objectives of (i) evaluating the effect of graded phosphorus levels on the grain and straw yield of rice grown in high-P soil, (ii) comparing the yield performance of four rice genotypes under these conditions, and (iii) examining the genotype $\times$ phosphorus interaction to identify the most suitable phosphorus dose and genotype combination for such soils.

2. Materials and Methods

A field experiment was conducted at College Farm, Rajendranagar, PJTAAU, Hyderabad during the Rabi season of 2025-26. Prior to layout, a composite surface soil sample was collected and analysed to characterise the initial fertility status of the experimental site, which was found to be high in available phosphorus and potassium, low in available nitrogen and deficient in available zinc (Table 4). The experiment was laid out in a Strip Plot Design with three replications. Factor A comprised five phosphorus levels - M1: control (no fertilizer or manure), M2: 50% of the recommended dose of phosphorus (30 kg P ha⁻¹), M3: 100% of the recommended dose (60 kg P ha⁻¹), M4: 150% of the recommended dose (90 kg P ha⁻¹) and M5: 200% of the recommended dose (120 kg P ha⁻¹) - applied as basal dose at transplanting. Factor B comprised four rice genotypes, namely DRR Dhan-78 (S1), WGL-1487 (S2), KNM-1638 (S3), and KPS-2874 (S4), raised following the recommended agronomic practices, uniformly across all treatments except the phosphorus dose.

Grain and straw yield were recorded from the net plot area at harvest, sun-dried to a uniform moisture content and expressed in kg ha⁻¹. Post-harvest soil samples were collected from each plot and analyzed for available nitrogen, phosphorus, potassium and zinc, and compared against the initial soil status recorded before layout. The data were subjected to analysis of variance appropriate to a Strip Plot Design, and treatment means were compared using the standard error of mean [SE(m)±] and critical difference [CD] at the 5% level of probability (Panse and Sukhatme, 1985) [7].

3. Results and Discussion

Phosphorus levels, genotypes, and their interaction had a highly significant effect on rice grain and straw yields (Tables 1 & 2). (Fig.1 & 2). These differences were reflected in the post-harvest nutrient status of the soil relative to its initial fertility (Tables 3 & 4).

3.1 Grain yield as influenced by phosphorus levels and genotypes

Grain yield increased significantly from the unfertilized control (M1, 4478 kg ha⁻¹) to the 50% RDP treatment (M2, 6784 kg ha⁻¹), representing the highest yield recorded among all phosphorus levels, and then declined progressively from the recommended dose (M3, 5247 kg ha⁻¹) to the 150% and 200% doses (M4, 4800 and M5, 4598

kg ha⁻¹). The observed optimum-and-decline trend indicated that the high native phosphorus status of the experimental soil, supplemented with 50% of the recommended dose of phosphorus, was adequate to meet the phosphorus requirement of the rice crop. Further increase in phosphorus application did not result in additional yield improvement and may have disturbed the balanced uptake of other essential nutrients. This response is in agreement with the findings of Brady and Weil (2017) [1], who reported that in soils with high residual phosphorus, additional phosphorus application often provides little agronomic benefit and may adversely affect nutrient balance.

Among genotypes, DRR Dhan-78 (S1) recorded the significantly highest grain yield (5594 kg ha⁻¹), which is on par with WGL-1487 (5288 kg ha⁻¹), followed by KNM-1638 (5054 kg ha⁻¹) and KPS-2874 (4789 kg ha⁻¹). Such genotypic differences in yield under a common phosphorus regime are well documented and generally attributed to differences in root system architecture, phosphatase activity, and internal phosphorus utilization efficiency among genotypes (Fageria and Baligar, 1997; Vellaikumar and Malarvizhi, 2017) [3, 9].

3.2 Straw yield as influenced by phosphorus levels and genotypes

Straw yield was significantly influenced by phosphorus levels and genotypes. The highest straw yield was recorded with 50% RDP (M2) (8817 kg ha⁻¹), which was significantly superior to all other treatments. The control (M1) recorded the lowest straw yield (5825 kg ha⁻¹), while straw yield declined progressively with increasing phosphorus application beyond 50% RDP, recording 6821, 6242 and 5981 kg ha⁻¹ under M3, M4 and M5, respectively. The trend in straw yield closely followed that of grain yield, indicating that excessive phosphorus application under high-phosphorus soils adversely affected overall biomass production rather than reproductive growth alone.

Among the genotypes, DRR Dhan-78 produced significantly higher straw yield (7272 kg ha⁻¹), followed by WGL-1487 (6875 kg ha⁻¹), KNM-1638 (6572 kg ha⁻¹) and KPS-2874 (6229 kg ha⁻¹). The superior straw yield of DRR Dhan-78 reflects its greater biomass production potential and better adaptation to high-phosphorus soil conditions.

3.3 Genotype $\times$ phosphorus level interaction

The genotype $\times$ phosphorus level interaction was significant for both grain and straw yield, indicating that genotypes did not respond uniformly to the imposed phosphorus levels (Tables 1 and 2). The single highest grain yield (7309 kg ha⁻¹) and straw yield (9497 kg ha⁻¹) recorded in the trial were both obtained from DRR Dhan-78 grown with 50% RDP, a combination that outperformed even the same genotype at the M3 (100% RDP). In contrast, KPS-2874 recorded comparatively low yield at every phosphorus level, including 50% RDP, reflecting a lower overall responsiveness of this genotype irrespective of phosphorus supply. Such differential genotype $\times$ phosphorus responses have been reported in other rice-based studies (Venkatesh *et al.*, 2020; Rose *et al.*, 2010) [8, 10] and these findings emphasize the importance of identifying the optimum phosphorus dose for individual genotypes under a given soil fertility status rather than adopting a uniform blanket fertilizer recommendation. A soil test-based and genotype-specific phosphorus management approach would enhance nutrient use efficiency, sustain crop productivity, and improve fertilizer use under high-phosphorus soils.

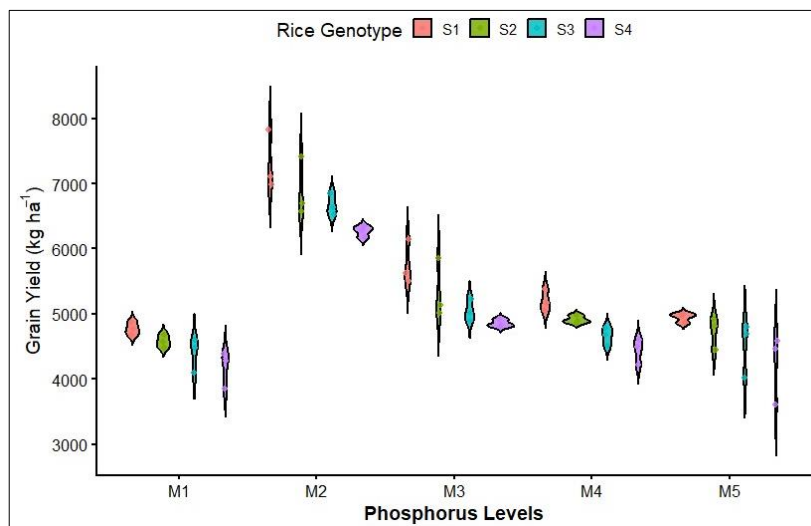


Fig 1: Grain yield of four rice genotypes as influenced by graded phosphorus levels in high-P soil

Table 1: Grain yield (kg ha^{-1}) of rice as influenced by phosphorus levels and genotypes in high-P soil

Phosphorus level	S1	S2	S3	S4	Mean (A)
M1 - Control	4772.78	4578.33	4388.33	4171.67	4478
M2 - 50% RDP (30 kg ha^{-1})	7308.67	6890.89	6669.78	6265.33	6784
M3 - 100% RDP (60 kg ha^{-1})	5755.33	5334.22	5046.44	4852.00	5247
M4 - 150% RDP (90 kg ha^{-1})	5194.22	4912.00	4657.56	4435.33	4800
M5 - 200% RDP (120 kg ha^{-1})	4939.78	4724.22	4506.44	4219.78	4598
Mean (B)	5594	5288	5054	4789	

Source	SE(m)±	CD (P=0.05)
Phosphorus level (A)	143.57	468.22
Genotype (B)	100.24	346.89
Genotypes at same P level	47.94	139.94
P levels at same genotype	149.46	436.23

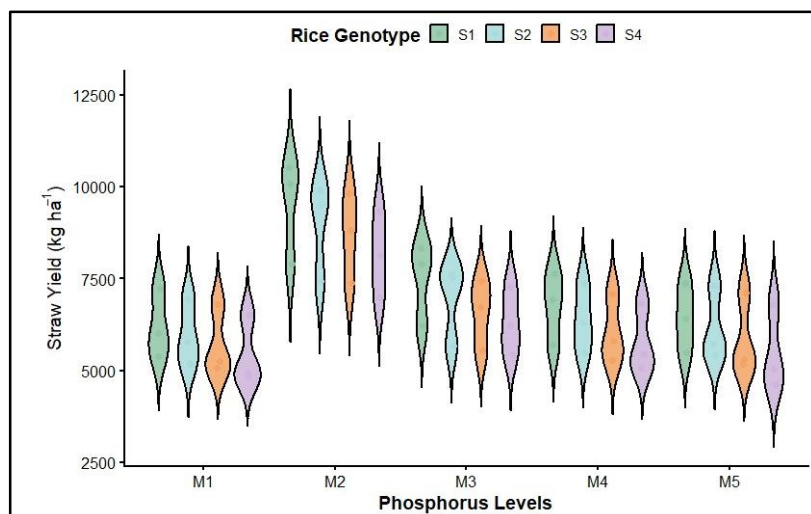


Fig 2: Straw yield of four rice genotypes as influenced by graded phosphorus levels in high-P soil

Table 2: Straw yield (kg ha^{-1}) of rice as influenced by phosphorus levels and genotypes in high-P soil

Phosphorus level	S1	S2	S3	S4	Mean (A)
M1 - Control	6207.00	5955.00	5709.00	5428.00	5825
M2 - 50% RDP (30 kg ha^{-1})	9497.00	8955.00	8670.00	8145.00	8817
M3 - 100% RDP (60 kg ha^{-1})	7480.00	6933.00	6561.00	6310.00	6821
M4 - 150% RDP (90 kg ha^{-1})	6753.00	6388.00	6058.00	5770.00	6242
M5 - 200% RDP (120 kg ha^{-1})	6423.00	6145.00	5864.00	5492.00	5981
Mean (B)	7272	6875	6572	6229	

Source	SE(m)±	CD (P=0.05)
Phosphorus level (A)	281.60	649.38
Genotype (B)	129.83	449.26
Genotypes at same P level	62.74	183.12
P levels at same genotype	206.40	602.45

3.4 Post-harvest soil nutrient status

Post-harvest soil available nitrogen and potassium were highest under 50% RDP (M_2) (141.70 and 404.92 kg ha⁻¹, respectively) and declined with further increases in phosphorus application, closely following the trend in grain and straw yield. In contrast, available soil phosphorus increased progressively from 54.34 mg kg⁻¹ in the control to 116.41 mg kg⁻¹ under 200% RDP, indicating residual phosphorus build-up due to low recovery and fixation of applied phosphorus in soil (Brady and Weil, 2017) [1]. Available soil zinc increased slightly up to 50% RDP (0.288 mg kg⁻¹) but declined sharply at higher phosphorus levels, reaching 0.108 mg kg⁻¹ under 200% RDP. This trend

indicates phosphorus-induced zinc deficiency resulting from the antagonistic interaction between phosphorus and zinc (Cakmak and Marschner, 1986) [2], which likely contributed to the decline in grain and straw yields beyond 50% RDP.

Among the genotypes, DRR Dhan-78 (S_1) recorded the highest residual soil available nitrogen (116.51 kg ha⁻¹), phosphorus (84.02 mg kg⁻¹) and zinc (0.291 mg kg⁻¹), despite producing the highest yield, indicating efficient nutrient acquisition and recycling. However, it recorded the lowest residual soil potassium (363.95 kg ha⁻¹), suggesting greater potassium removal and the need for genotype-specific potassium management.

Table 3: Post-harvest soil available N, K, P and Zn as influenced by phosphorus levels and genotypes

Treatment	N (kg ha ⁻¹)	K (kg ha ⁻¹)	P (mg kg ⁻¹)	Zn (mg kg ⁻¹)
Factor A - Phosphorus levels				
M1 - Control	77.19	211.74	54.34	0.247
M2 - 50% RDP (30 kg ha ⁻¹)	141.7	404.92	64.81	0.288
M3 - 100% RDP (60 kg ha ⁻¹)	126.84	393.32	75.28	0.27
M4 - 150% RDP (90 kg ha ⁻¹)	116.81	328.98	87.04	0.208
M5 - 200% RDP (120 kg ha ⁻¹)	85.92	297.83	116.41	0.108
S.E(m)±	2.32	0.11	0.73	0.030
CD (P=0.05)	7.56	0.37	2.39	0.099
Factor B - Genotypes				
S1 - DRR Dhan-78	116.51	363.95	84.02	0.291
S2 - WGL-1487	111.88	332.05	79.95	0.217
S3 - KNM-1638	107.3	317.15	78.04	0.216
S4 - KPS-2874	103.08	396.29	76.29	0.174
S.E(m)±	1.21	0.10	0.20	0.013
CD (P=0.05)	4.19	0.35	0.70	0.046

3.5 Comparison of initial and post-harvest soil nutrient status

The experimental soil was initially high in available phosphorus (90.2 kg P₂O₅ ha⁻¹) and potassium (287.3 kg K₂O ha⁻¹), low in available nitrogen (153.7 kg ha⁻¹), and marginally deficient in available zinc (0.431 mg kg⁻¹), which was below the critical limit of 0.6 mg kg⁻¹ (Lindsay and Norvell, 1978) [5]. This confirmed the high-phosphorus nature of the soil with limited zinc reserves.

Compared with the initial status, post-harvest available nitrogen declined under all treatments, with the least reduction under 50% RDP (M_2 ; 141.70 kg ha⁻¹, 7.8%) and the greatest under the control (M_1 ; 49.8%) and 200% RDP (M_5 ; 44.1%). Available potassium declined below the initial level only in the control, whereas all phosphorus-treated

plots maintained higher potassium, with the maximum under 50% RDP (404.92 kg ha⁻¹; 40.9% increase). These trends closely paralleled the grain and straw yield response.

Available zinc declined under all treatments and the reduction increased progressively from 33.2% under 50% RDP (0.288 mg kg⁻¹) to 74.9% under 200% RDP (0.108 mg kg⁻¹), indicating phosphorus-induced zinc deficiency at higher phosphorus levels (Cakmak and Marschner, 1986) [2]. Although initial and post-harvest phosphorus values were expressed in different units and are not directly comparable, post-harvest available phosphorus increased from 54.34 to 116.41 mg kg⁻¹ with increasing phosphorus application, confirming the accumulation of residual phosphorus in the soil.

Table 4: Initial (pre-sowing) soil available N, P, K and Zn status of the experimental site

Soil parameter	Value
Available Nitrogen (kg ha ⁻¹)	153.7
Available Phosphorus (kg ha ⁻¹)	90.2
Available Potassium (kg ha ⁻¹)	287.3
Available Zinc (mg kg ⁻¹)	0.431

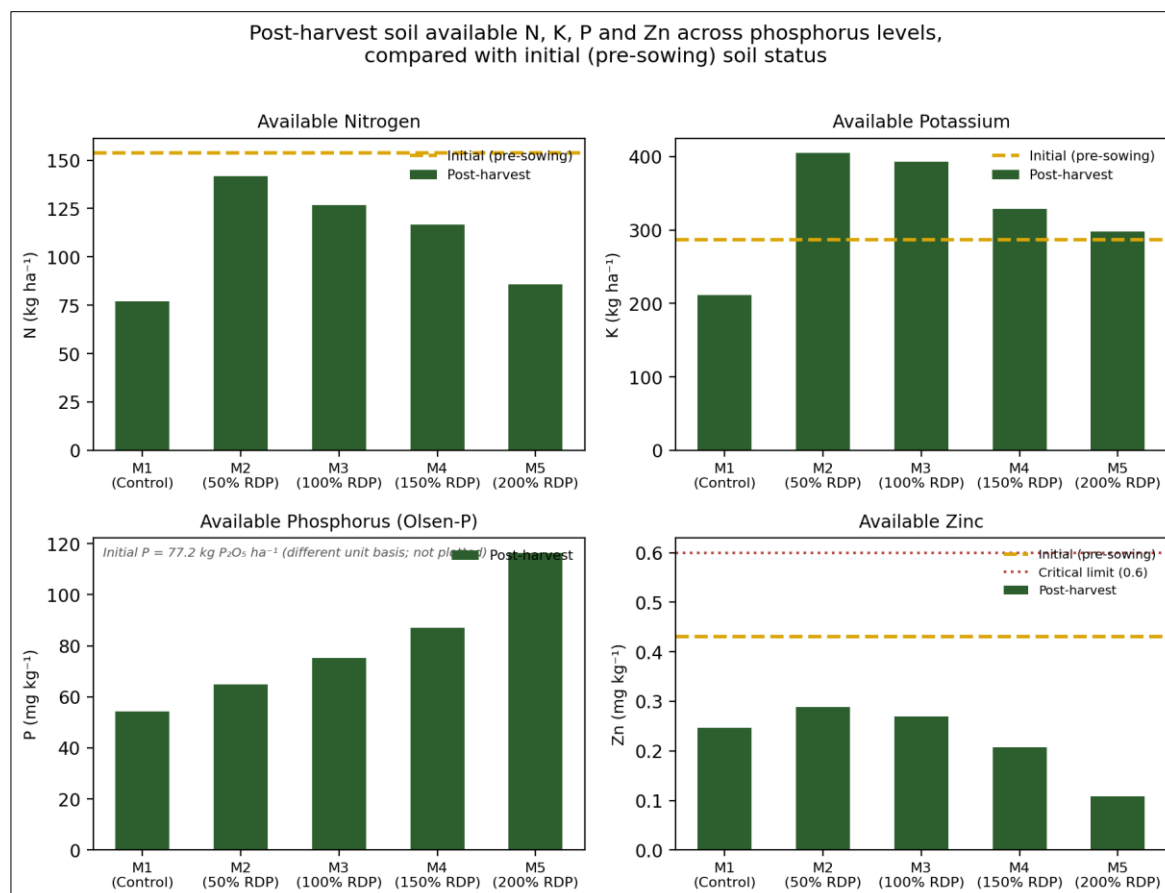


Fig 3: Post-harvest soil available N, K, P and Zn across phosphorus levels, compared with initial (pre-sowing) soil status

4. Conclusion

The present investigation revealed that in soils initially high in available phosphorus and potassium, low in available nitrogen, and marginally deficient in available zinc, application of 50% RDP was sufficient to achieve the highest grain and straw yield of rice. Higher phosphorus levels beyond 50% RDP progressively reduced yield and intensified zinc depletion. Among the genotypes, DRR Dhan-78 recorded the highest productivity, particularly under 50% RDP. The findings suggest that soil test-based phosphorus management using 50% RDP, together with a phosphorus-efficient genotype and appropriate zinc management, can sustain rice productivity, improve phosphorus use efficiency, reduce fertilizer costs, and minimize nutrient imbalance in high-phosphorus soils.

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