

Original Research Article

Sustainable Management of Phosphorus on Performance of Rice - Zero till Maize (*Zea mays* L.) Cropping System

ABSTRACT

Aims: To study the phosphorus levels in Rice - zero till maize (*zea mays* l.) cropping system on yield, nutrient uptake and post-harvest soil nutrient status.

Study design: Two factors Randomized block design.

Methodology: Field investigation was organized during two consecutive years at College of Agriculture, Rajendranagar, Hyderabad. Levels of P_2O_5 ($kg\ ha^{-1}$) applied to rice (5) and maize (3) respectively were (P_{0-30} , P_{0-45} , P_{0-60} , P_{10-30} , P_{10-45} , P_{10-60} , P_{20-30} , P_{20-45} , P_{20-60} , P_{30-30} , P_{30-45} , P_{30-60} , P_{40-30} , P_{40-45} and P_{40-60}).

Results: Direct effect of $20\ kg\ P_2O_5\ ha^{-1}$ to rice, being on par with 30 and $40\ kg\ P_2O_5\ ha^{-1}$, produced significantly higher grain and straw yield of rice, uptake of nutrients over rest of the treatments. The residual effect of Phosphorus applied to maize @ $60\ kg\ P_2O_5\ ha^{-1}$ resulted in significantly higher above said parameters of rice. The cumulative effect of P_{20-60} produced significantly higher grain and straw yield, nutrient uptake of rice over P_{10-30} , P_{10-45} , P_{0-30} , P_{0-45} and P_{0-60} treatments.

Direct effect of $60\ kg\ P_2O_5\ ha^{-1}$ to maize recorded significantly higher grain and stover yield, nutrient uptake and available soil phosphorus over lower Phosphorus levels; but the soil nitrogen and potassium followed reverse trend. The residual effect of 40 and /or $30\ kg\ P_2O_5\ ha^{-1}$ applied to rice had a greater positive influence on the above said parameters except soil nitrogen and potassium over lower phosphorus levels. The cumulative effect of P_{40-60} and P_{30-60} had produced significantly higher grain and stover yield and nutrient uptake of maize and showed significantly higher available soil phosphorus at the end as compared to the rest of the treatments; emphasizing application of $30\ kg\ P_2O_5\ ha^{-1}$ to rice and $60\ kg\ P_2O_5\ ha^{-1}$ to maize through P_{30-60} treatment in rice-zero till maize cropping system to maintain phosphorus sustainability.

Keywords: Maize; Phosphorus; rice, uptake; yield; zero tillage

1. INTRODUCTION

Rice-maize is the leading cropping system occupying in an area of $3.5\ m\ ha$ in Asia after the Rice-rice and rice-wheat cropping system [30]. Diversification to maize could also be a good strategy for adaptation to climate change, as it is more tolerant to high temperatures when compared to wheat. Rice-maize cropping system is rapidly expanding in south Asia comprising India due to its potential from *rabi* maize, and its reduced water requirement compared to rice-rice system and its multiple uses.

In command areas *rabi* maize sowings are being delayed when farmers resort for conventional land preparation resulting in lower yields, thereby 'late planting' has become a major constraint. These yield declines due to late planting can be eluded by sowing maize under zero tillage after harvesting of rice crop. Zero tillage would reduce the potential for soil erosion and loss of soil organic matter [12]. Besides the soil and water conservation, fuel consumption, labour requirement and turnaround time.

Among the various nutrients, Phosphorus is one of the costly and most limiting key nutrients in agricultural cropping systems [7, 11, 24 and 21]. Scheduling fertilizer to cropping systems rather than single crop basis help its efficient application and economizing expenses [13, 19, and 20]. If fertilizers are not supplemented as per the necessities for high yield of maize there is an opportunity for nutrient mining. Perfect Phosphorus drawn factors could be derived for each soil and crop growing environments whereby yield could be optimized without substantial mining of nutrients from the soil [2]. Therefore, management practices relying on intensive cropping sequences require comprehensive information on nutrient fluctuations in the soil to better manage additional fertility requirements of the subsequent crop.

Soil physical and chemical properties and associated management for alternating wetting and drying environments of Rice-Wheat system that could be well applied to Rice-Maize system too [8, 18, 24, 25, 29 and 29]. It is reported that Rice-Maize system is quite diverse from Rice-Wheat or Rice-Rice system in nutrient withdrawal, which would be much superior due to greater yield of maize.

In rice and other ID crops in rice-based cropping systems, alternate wetting and drying during *rabi* season lessens native Phosphorus availability to ID crops like maize and increases crop response to applied Phosphorus. Application of phosphatic fertilizers to *rabi* season crops and growing *kharif* season crops on residual fertility has been advocated in most of the soils, wheat being a winter crop, responds more to phosphorus application than wet season rice [6]. Efficient utilization of nutrient Phosphorus, residual and cumulative effects of Phosphorus should be deliberated while framing fertilizer use recommendations in diverse cropping sequences [5].

Even though numerous technologies have been established for rice-wheat rotation, the same may not be appropriate for rice-zero tillage maize situations particularly on Phosphorus requirements. Keeping these facts in attention the current study was structured to probe the direct, residual and cumulative influence of phosphatic fertilizer application on the performance of crops in rice-zero till maize cropping system that would improve the productivity and sustainability of system.

2. MATERIAL AND METHODS

The study was conducted in the College farm situated at College of Agriculture, Rajendranagar, Hyderabad, Telangana, India (17° 19' North latitude, 78° 27' East longitude and 542.6 m above mean sea level). The soil at the experimental site was a well drained sandy clay loam [17] with 61.56 g sand, 15.58 g silt and 22.6 g clay per 100g soil in the surface horizon. Initial soil properties of composite samples taken from 0 to 15 cm soil depth were with 0.63% Organic carbon [31], 8.33 pH [10], 0.46 dSm⁻¹ electrical conductivity [10], 197.50 kg ha⁻¹ available Nitrogen [28], 16.96 kg ha⁻¹ available Phosphorus [14] and 163.5 kg ha⁻¹ available Potassium [9]. Research was conducted with rice and zero tillage maize respectively, during *kharif* and *rabi* seasons.

The experiment was laid out in two factorial randomized block design with three replications at five Phosphorus levels to rice namely; F₁: No Phosphorus, F₂: 10 kg P₂O₅ ha⁻¹, F₃: 20 kg P₂O₅ ha⁻¹, F₄: 30 kg P₂O₅ ha⁻¹ and F₅: 40 kg P₂O₅ ha⁻¹ and three phosphorus levels to maize namely; P₁: 30 kg P₂O₅ ha⁻¹, P₂: 45 kg P₂O₅ ha⁻¹ and P₃: 60 kg P₂O₅ ha⁻¹. The P₂O₅ (kg ha⁻¹) levels applied to rice and zero tillage maize respectively in different treatments were (T₁: P₀₋₃₀, T₂: P₀₋₄₅, T₃: P₀₋₆₀, T₄: P₁₀₋₃₀, T₅: P₁₀₋₄₅, T₆: P₁₀₋₆₀, T₇: P₂₀₋₃₀, T₈: P₂₀₋₄₅, T₉: P₂₀₋₆₀, T₁₀: P₃₀₋₃₀, T₁₁: P₃₀₋₄₅, T₁₂: P₃₀₋₆₀, T₁₃: P₄₀₋₃₀, T₁₄: P₄₀₋₄₅ and T₁₅: P₄₀₋₆₀).

After puddling operation rice seedlings of MTU 1010 variety were transplanted in the plots during *kharif* season of first year by adopting a spacing of 20 cm x 10 cm at shallow depth of 2-3 cm. Likewise, the rice seedlings during *kharif* season of the succeeding year were also planted in the same plots without disturbing the layout of previous year. The entire quantity of phosphorus according to treatments through single super phosphate and entire recommended potassium as Muriate of Potash were incorporated basally into the soil before last puddling. Recommended rate of Nitrogen was applied in equal splits at transplanting; maximum tillering and at panicle initiation stage of rice. All other recommended agronomic practices were followed uniformly for all the experimental plots of rice.

The Maize hybrid (Super 900M) seeds were dibbled under zero tillage condition by adopting a spacing of 60 cm and 20 cm during *rabi* season during consecutive years in the same plots without disturbing the layout of previous *kharif* season rice. The entire quantity of P₂O₅ according to treatments through single super phosphate and the entire recommended dose of Potassium as Muriate of Potash were applied in bands at 5 cm away and 5 cm below the seed at the time of sowing. The recommended dose of Nitrogen was applied as Urea in three equal split doses at basal and top dressing at knee high and tasselling stage of the maize crop. Paraquat @ 1.5 kg a.i.ha⁻¹ was applied to the entire field after harvesting of rice crop to control the existing weeds and to prevent the re-growth of rice stubble. One day after sowing of maize seeds, pre emergence herbicide (Atrazine) was applied at recommended rate to the entire field. No irrigation was

given after sowing of the crop as there was sufficient residual soil moisture. Subsequent need based irrigations and all other agronomic practices were followed uniformly for all the experimental plots.

The grain and straw yield of rice and grain and stover yield of maize were quantified separately from samples collected in a 16.64 m² area in rice and 10.56 m² area in maize and converted to kg ha⁻¹. Grain yields were adjusted to moisture content of 0.14 kg moisture kg⁻¹ grain. Samples collected at harvest were shade dried followed by oven drying at 60°C to attain a constant weight. Samples of grain and straw of rice and grain and stover maize were finely ground and used for nutrient analysis (Nitrogen, Phosphorus and Potassium content) by adopting standard procedures. The finely ground samples were digested with tri-acid mixture (Nitric acid, Sulphuric acid and Perchloric acid in 9: 4:1 ratio) and was used for Phosphorus estimation by Vanado-Molybdo Phosphoric acid method (10) and Potassium content in the tri-acid extract was estimated by using ELICO flame photometer. Nutrient uptake (Nitrogen, Phosphorus & Potassium) by grain and stover was obtained by multiplying the respective nutrient concentration with their respective grain and stover yield of maize and with seed and straw yield of rice to obtain uptake by rice grain and straw, respectively.

After the harvest of crops at the end of each season, treatment wise soil samples collected from 0–30 cm depth were air dried and analysed for available nutrient status (Nitrogen, Phosphorus & Potassium) by following standard procedures [17]. Available Phosphorus of the soil samples were extracted with Olsen's extractant (0.5 M NaHCO₃). Phosphorus in the extractant was estimated colorimetrically by Ascorbic acid method [14] and was expressed as kg of Phosphorus ha⁻¹ after adjusting for bulk density.

2.3. Analysis of Variance (ANOVA)

Analysis of variance was carried out for each character separately as per standard statistical procedure for two factor randomized block design as suggested by the Panse and Sukhatme [15]. Wherever the treatment differences were found significant critical differences were worked out at five % probability level (P=0.05) and treatment differences that were non-significant were denoted by 'NS'.

3. RESULTS AND DISCUSSION

The data on influence of different levels of phosphorus application in rice-maize sequence on grain yield of rice is presented in table 1.

3.1 Effect on Rice Yield:

3.1.1 Direct effect on rice grain yield

The increase in Phosphorus level from 0 to 40 kg P₂O₅ ha⁻¹ to rice with an increment of 10 kg P₂O₅ ha⁻¹ significantly increased the grain yield of rice up to 20 kg P₂O₅ ha⁻¹; the increased Phosphorus beyond this level did not increase the grain yield significantly. Application of 40 kg P₂O₅ ha⁻¹ gave a grain yield of 5341 and 5113 kg ha⁻¹ respectively in first and second years, followed by 30 kg P₂O₅ ha⁻¹ (5253 and 5082 kg ha⁻¹), 20 kg P₂O₅ ha⁻¹ (5240 and 5008 kg ha⁻¹), 10 kg P₂O₅ ha⁻¹ (4835 and 4686 kg ha⁻¹) and no phosphorus (4462 and 4548 kg ha⁻¹) treatment [3, 22, and 27].

3.1.2 Direct effect on rice straw yield

The increase in P level to rice from 0 to 40 kg P₂O₅ ha⁻¹ significantly increased the straw yield of rice up to 20 kg P₂O₅ ha⁻¹ in both the years. Direct application of 20 kg P₂O₅ ha⁻¹ to rice recorded significantly higher straw yield (5829 and 5825 kg ha⁻¹) over 10 kg P₂O₅ ha⁻¹ and no phosphorus in first and second years, respectively, however it did not differ significantly with 30 and 40 kg P₂O₅ ha⁻¹ in both years. These results corroborate the findings of many researchers [3, 16, 22, 26, and 27].

Table 1: Direct, residual and cumulative effect of phosphorus levels in rice-maize cropping system on grain and straw yield of rice.

Treatments	Rice grain yield (kg ha ⁻¹)		Rice Straw yield (kg ha ⁻¹)	
	First Year	Second Year	First Year	Second Year
Direct (Kharif Rice)				
F ₁ :No Phosphorus	4462	4548	5136	5331

F ₂ : 10 kg P ₂ O ₅ ha ⁻¹	4835	4686	5545	5440
F ₃ : 20 kg P ₂ O ₅ ha ⁻¹	5240	5008	5829	5825
F ₄ : 30 kg P ₂ O ₅ ha ⁻¹	5253	5082	5867	5893
F ₅ : 40 kg P ₂ O ₅ ha ⁻¹	5341	5113	5906	5912
SE(m) ±	38	40	27	32
C.D.(P = 0.05)	109	116	78	94
Residual (Rabi Maize)				
P ₁ : 30 kg P ₂ O ₅ ha ⁻¹	-	4730	-	5562
P ₂ : 45 kg P ₂ O ₅ ha ⁻¹	-	4899	-	5683
P ₃ : 60 kg P ₂ O ₅ ha ⁻¹	-	5034	-	5795
S.Em.±	-	31	-	25
C.D.(P = 0.05)	-	90	-	73
Phosphorus levels to rice and maize				
P ₀₋₃₀	-	4246	-	5125
P ₀₋₄₅	-	4566	-	5332
P ₀₋₆₀	-	4833	-	5537
P ₁₀₋₃₀	-	4425	-	5225
P ₁₀₋₄₅	-	4687	-	5430
P ₁₀₋₆₀	-	4946	-	5665
P ₂₀₋₃₀	-	4940	-	5721
P ₂₀₋₄₅	-	4977	-	5849
P ₂₀₋₆₀	-	5108	-	5903
P ₃₀₋₃₀	-	5001	-	5870
P ₃₀₋₄₅	-	5118	-	5893
P ₃₀₋₆₀	-	5127	-	5917
P ₄₀₋₃₀	-	5036	-	5870
P ₄₀₋₄₅	-	5148	-	5910
P ₄₀₋₆₀	-	5155	-	5955
SE(m) ±	-	70	-	56
C.D.(P = 0.05)	-	201	-	163

3.1.3 Residual effect on rice grain yield

The residual effect of previous year applied Phosphorus in rice-maize sequence on the grain yield of second year rice was found significant [22, 26, and 27]. Application of 60 kg P₂O₅ ha⁻¹ to maize during first year produced significantly higher grain yield of rice (5034 kg ha⁻¹) over 45 kg P₂O₅ ha⁻¹ (4899 kg ha⁻¹) and 30 kg P₂O₅ ha⁻¹ (4730 kg ha⁻¹).

3.1.4 Residual effect on rice straw yield

The residual effect on the straw yield of rice during second year was significant [3, 26, and 27]. Application of 60 kg P₂O₅ ha⁻¹ to maize in first year produced significantly higher straw yield of rice (5795 kg ha⁻¹) over 45 kg P₂O₅ ha⁻¹ (5683 kg ha⁻¹) and 30 kg P₂O₅ ha⁻¹ (5562 kg ha⁻¹).

3.1.5 Cumulative effect on rice grain yield

The interaction of 'Phosphorus' levels in rice and maize during second year indicated that addition of 20 kg P₂O₅ ha⁻¹ to rice through P₂₀₋₆₀ treatment resulted in higher grain yield of rice over application of 10 kg P₂O₅ ha⁻¹ (P₁₀₋₃₀ and P₁₀₋₄₅) and no phosphorus treatment (P₀₋₃₀ and P₀₋₄₅ and P₀₋₆₀). However, it was found on par to that of application of 30 kg P₂O₅ ha⁻¹ (P₃₀₋₃₀, P₃₀₋₄₅ and P₃₀₋₆₀) and 60 kg P₂O₅ ha⁻¹ (P₄₀₋₃₀, P₄₀₋₄₅ and P₄₀₋₆₀) to rice [3, 16, 22, 26, 27]. This less response of rice to current season applied Phosphorus and its significant response to residual Phosphorus might be due to increased availability of residual Phosphorus under submerged conditions of rice. The increased availability of Phosphorus in flooded rice is due to enhanced 'Phosphorus' solubility owing to reduction of Fe⁺³ compounds and increased solubility of Ca-P because of decreased pH [4, 22, 18, 25, 32] besides, root-induced solubilization of acid soluble Phosphorus by rice [24]. This was also evident from the increased uptake of 'Phosphorus' due to graded Phosphorus levels in the present investigation, but they did not consistently improve rice yields in parity with Phosphorus uptake; probably because of reduced sorption and enhanced dissolution of 'Phosphorus' might have increased the 'Phosphorus' supply to rice showing this kind of response.

3.1.6 Cumulative effect on rice straw yield

The interaction of 'Phosphorus' levels in rice and maize during second year indicated that application of 20 kg P₂O₅ ha⁻¹ to rice through P₂₀₋₆₀ treatment resulted in higher straw yield of rice over application of 10 kg P₂O₅ ha⁻¹ (P₁₀₋₃₀, P₁₀₋₄₅ and P₁₀₋₆₀) and no phosphorus treatment (P₀₋₃₀, P₀₋₄₅ and P₀₋₆₀). However, it was found on par to that of application of 30 kg P₂O₅ ha⁻¹ (P₃₀₋₃₀, P₃₀₋₄₅ and P₃₀₋₆₀) and 40 kg P₂O₅ ha⁻¹ (P₄₀₋₃₀, P₄₀₋₄₅ and P₄₀₋₆₀) to rice in rice-maize sequence. Similar findings were also reported by many researchers [5, 13, 22, 27, 33].

3.2 Effect on Maize Yield:

3.2.1 Direct effect on maize grain yield

The grain yield of maize increased from 4436 and 4447 kg ha⁻¹ by direct application of 30 kg P₂O₅ ha⁻¹ to 4830 and 4836 kg ha⁻¹ by the application of 45 kg P₂O₅ ha⁻¹ in first and second years, respectively (table 2). It improved significantly to a maximum of 5144 and 5198 kg ha⁻¹ by the application of 60 kg P₂O₅ ha⁻¹ in the corresponding years [19, 20].

3.2.2 Direct effect on maize stover yield

Stover yield as influenced by different phosphorus levels to rice and maize is presented in table 2. Analogous to grain yield, the stover yield of maize improved significantly from 6469 and 6272 kg ha⁻¹ by direct application of 30 kg P₂O₅ ha⁻¹ to 6988 and 6816 kg ha⁻¹ by the application of 45 kg P₂O₅ ha⁻¹ and to 7324 and 7234 kg ha⁻¹ by application of 60 kg P₂O₅ ha⁻¹ in two years, respectively. These findings confirm the findings of other researchers [19, 20].

Table 2: Direct, residual and cumulative effect of phosphorus levels in rice-maize cropping system on grain and stover yield of maize.

Treatments	Grain yield (kg ha ⁻¹)		Stover yield (kg ha ⁻¹)	
	First Year	Second Year	First Year	Second Year
Direct (Rabi Maize)				
P ₁ : 30 kg P ₂ O ₅ ha ⁻¹	4436	4447	6469	6272
P ₂ : 45 kg P ₂ O ₅ ha ⁻¹	4830	4836	6988	6816
P ₃ : 60 kg P ₂ O ₅ ha ⁻¹	5144	5198	7324	7234
S.E.m.±	32	41	46	48
C.D.(P = 0.05)	94	120	132	140
Residual (Kharif Rice)				
F ₁ :No Phosphorus	4585	4570	6679	6495
F ₂ : 10 kg P ₂ O ₅ ha ⁻¹	4692	4711	6817	6691
F ₃ : 20 kg P ₂ O ₅ ha ⁻¹	4706	4726	6849	6744
F ₄ : 30 kg P ₂ O ₅ ha ⁻¹	4937	5032	7063	6922
F ₅ : 40 kg P ₂ O ₅ ha ⁻¹	5097	5094	7227	7017
SE(m) ±	42	53	59	63
C.D.(P = 0.05)	121	154	170	181
Phosphorus levels to rice and maize				
P ₀₋₃₀	4056	3961	5955	5670
P ₀₋₄₅	4677	4678	6822	6726
P ₀₋₆₀	5022	5072	7259	7090
P ₁₀₋₃₀	4280	4286	6322	6180
P ₁₀₋₄₅	4726	4727	6926	6784
P ₁₀₋₆₀	5071	5120	7202	7109
P ₂₀₋₃₀	4290	4295	6375	6291
P ₂₀₋₄₅	4752	4755	6904	6768
P ₂₀₋₆₀	5076	5128	7267	7174
P ₃₀₋₃₀	4704	4819	6824	6584
P ₃₀₋₄₅	4894	5005	7038	6896
P ₃₀₋₆₀	5213	5272	7328	7285
P ₄₀₋₃₀	4850	4872	6869	6633
P ₄₀₋₄₅	5103	5013	7248	6906
P ₄₀₋₆₀	5339	5398	7565	7512
SE(m) ±	72	92	102	108

3.2.3 Residual effect on maize grain yield

The residual effect of phosphorus applied at 30 kg P₂O₅ ha⁻¹ to rice recorded significantly higher grain yield of maize (4937 and 5032 kg ha⁻¹) during two years of investigation over lower phosphorus levels. However, the residual effect of 30 and 40 kg P₂O₅ ha⁻¹ was found on par [1, 26, 33and 33].

3.2.4 Residual effect on maize stover yield

The stover yield of maize also followed same trend due to residual effect of Phosphorus applied to rice. It increased significantly with increased phosphorus application to rice up to 30 kg P₂O₅ ha⁻¹, there after the increase was not significant in both years [1, 26, 33and 33].

3.2.5 Cumulative effect on maize grain yield

There was a pronounced interaction effect of levels of phosphorus applied to maize and rice in rice-maize sequence on the grain yield of maize during both the years of experimentation. The maize crop gave 5340 and 5400 kg grain yield ha⁻¹ in first and second years, respectively when recommended dose of Phosphorus was applied to rice and maize through P₄₀₋₆₀ treatment. Nevertheless, P₄₀₋₆₀ was found at par with P₃₀₋₆₀ (5210and 5270 kg ha⁻¹) and resulted in significantly higher grain yield over rest of the treatment combinations [1, 8, 6, 27and 27].

3.2.6 Cumulative effect on maize stover yield

The treatment P₄₀₋₆₀ being on par with P₃₀₋₆₀ (7328 and 7285 kg ha⁻¹) recorded significantly higher stover yield (7565 and 7512 kg ha⁻¹) over other treatment combinations. Similar kind of response was observed in wheat following wet season rice by [5,23,32] and stated that upland crop (wheat) after rice, responds to higher Phosphorus application because of reduced 'Phosphorus' availability due to moisture regime and low temperature during winter season. The increase in grain and stover yield of maize with increased phosphorus levels has been reported by several workers [1, 8, 6, 27and 27].

3.3 Uptake of Nutrients

The uptake of Nitrogen, Phosphorus and Potassium by rice as influenced by different levels of phosphorus application in rice-maize sequence is presented in table 3.

3.3.1 Uptake of Nitrogen by rice

3.3.1.1 Direct effect:

Application of 20 kg P₂O₅ ha⁻¹ to rice recorded significantly higher uptake of Nitrogen (91.81 and 95.34 kg ha⁻¹) as compared to no phosphorus and 10 kg P₂O₅ ha⁻¹, however it was found on par with 30 and 40 kg P₂O₅ ha⁻¹; except to the first year, which was significantly lower to 30 and 40 kg P₂O₅ ha⁻¹. The differences in uptake of Nitrogen between 0 and 10 kg P₂O₅ ha⁻¹ were also significant [3, 22, 27and 27].

3.3.1.2 Residual effect

The residual effect of previous year applied Phosphorus to rice-maize on uptake of Nitrogen showed that application of 60 kg P₂O₅ ha⁻¹ to maize showed significantly higher uptake of 95.30 kg ha⁻¹ over 45 and 30 kg P₂O₅ ha⁻¹ [3, 22, 27and 27].

3.3.1.3 Cumulative effect

The interaction of 'Phosphorus' levels in rice and maize during second year indicated that application of 40 kg P₂O₅ ha⁻¹ to rice through P₄₀₋₆₀ treatment significantly increased the uptake of nitrogen by rice over the treatments of P₀₋₃₀, P₀₋₄₅, P₀₋₆₀, P₁₀₋₃₀, P₁₀₋₄₅ and P₁₀₋₆₀; however it was found at par with rest of the treatments (P₂₀₋₃₀, P₂₀₋₄₅, P₂₀₋₆₀, P₃₀₋₃₀, P₃₀₋₄₅, P₃₀₋₆₀, P₄₀₋₃₀, P₄₀₋₄₅).

Table 3: Effect of phosphorus levels in rice-maize cropping system on uptake (kg ha⁻¹) of Nitrogen, Phosphorus and Potassium at harvest of rice

Treatments	Nitrogen		Phosphorus		Potassium	
	First Year	Second Year	First Year	Second Year	First Year	Second Year
Direct (Kharif)						
F ₁ :No Phosphorus	76.47	85.59	15.67	16.85	75.16	68.23
F ₂ : 10 kg P ₂ O ₅ ha ⁻¹	83.67	88.14	18.05	17.48	81.73	69.99
F ₃ : 20 kg P ₂ O ₅ ha ⁻¹	91.81	95.34	20.05	19.04	87.55	76.78
F ₄ : 30 kg P ₂ O ₅ ha ⁻¹	92.99	96.22	20.77	19.39	88.71	77.86
F ₅ : 40 kg P ₂ O ₅ ha ⁻¹	93.89	96.84	21.53	19.54	88.88	78.12
SE(m) ±	0.60	0.52	0.14	0.11	0.38	0.36

C.D.(P = 0.05)	1.75	1.52	0.40	0.32	1.09	1.04
Residual (Rabi)						
P ₁ : 30 kg P ₂ O ₅ ha ⁻¹	-	89.54	-	16.93	-	72.25
P ₂ : 45 kg P ₂ O ₅ ha ⁻¹	-	92.45	-	18.83	-	74.27
P ₃ : 60 kg P ₂ O ₅ ha ⁻¹	-	95.30	-	19.63	-	76.07
S.Em.±	-	0.41	-	0.08	-	0.28
C.D.(P = 0.05)	-	1.17	-	0.25	-	0.80
Phosphorus levels to rice and maize						
P ₀₋₃₀	-	79.82	-	14.88	-	64.96
P ₀₋₄₅	-	85.89	-	17.30	-	68.27
P ₀₋₆₀	-	91.07	-	18.38	-	71.46
P ₁₀₋₃₀	-	83.19	-	15.56	-	66.76
P ₁₀₋₄₅	-	88.11	-	17.84	-	69.88
P ₁₀₋₆₀	-	93.12	-	19.04	-	73.33
P ₂₀₋₃₀	-	93.53	-	17.78	-	75.17
P ₂₀₋₄₅	-	95.09	-	19.29	-	77.00
P ₂₀₋₆₀	-	97.42	-	20.06	-	78.16
P ₃₀₋₃₀	-	95.35	-	18.10	-	77.05
P ₃₀₋₄₅	-	96.31	-	19.76	-	78.02
P ₃₀₋₆₀	-	97.00	-	20.31	-	78.52
P ₄₀₋₃₀	-	95.78	-	18.32	-	77.31
P ₄₀₋₄₅	-	96.86	-	19.96	-	78.17
P ₄₀₋₆₀	-	97.88	-	20.35	-	78.88
SE(m) ±	-	0.91	-	0.19	-	0.62
C.D.(P = 0.05)	-	2.63	-	0.55	-	1.79

3.3.2- Uptake of Phosphorus by rice

3.3.2.1 Direct effect

Application of 40 kg P₂O₅ ha⁻¹ to rice recorded significantly higher uptake 21.53 kg ha⁻¹ over lower phosphorus levels [3, 22, 27] during the first year. While in second year 30 kg P₂O₅ ha⁻¹ recorded significantly higher uptake 19.39 kg ha⁻¹ over lower phosphorus levels; however it was found at par with 40 kg P₂O₅ ha⁻¹ (19.55 kg ha⁻¹).

3.3.2.2 The residual effect

The residual effect on Phosphorus uptake of rice in second year showed that application 60 kg P₂O₅ ha⁻¹ to maize resulted in significantly higher uptake (19.63 kg ha⁻¹) over 45 and 30 kg P₂O₅ ha⁻¹ [3, 22, 27].

3.3.2.3 Cumulative effect

The interaction of 'Phosphorus' levels in rice and maize during second year showed that application of 40 kg P₂O₅ ha⁻¹ to rice through P₄₀₋₆₀ treatment showed significantly higher phosphorus uptake by rice over rest of the treatments; however it was found at a par with P₄₀₋₃₀, P₄₀₋₄₅ and P₃₀₋₆₀. The greater nutrient uptake values with higher levels of phosphorus were due to higher grain and straw yields. These results confirm the findings of [3, 5, 8, and 22].

3.3.3 Uptake of Potassium by rice

The uptake of potassium by rice as influenced by different levels of phosphorus in rice-maize sequence is presented in table 3.

3.3.3.1 Direct effect

Direct application of 30 kg P₂O₅ ha⁻¹ to rice recorded higher uptake (88.71 and 77.86 kg ha⁻¹) compared to no Phosphorus, 10 and 20 kg P₂O₅ ha⁻¹ in first and second years, respectively. Application of 20 kg P₂O₅ ha⁻¹ increased Potassium uptake of rice by 1.36, 8.54 and 18.03 % during first year and 1.41, 11.24 and 14.11 % in second year over 20 kg P₂O₅ ha⁻¹, 10 kg P₂O₅ ha⁻¹ to and no phosphorus, respectively.

3.3.3.2 Residual effect

The residual effect of preceding year applied phosphorus was significant on uptake of Potassium. Application of 60 kg P_2O_5 ha^{-1} to maize showed significantly higher uptake ($kg\ ha^{-1}$) (76.07) over 45 kg P_2O_5 ha^{-1} (74.27) and 30 kg P_2O_5 ha^{-1} (72.25) in second year [3, 22, 27].

3.3.3.3 Cumulative effect

The interaction of 'Phosphorus' levels in rice and maize during second year indicated that application of 40 kg P_2O_5 ha^{-1} to rice through P_{40-60} treatment resulted in significantly higher potassium uptake by rice over P_{0-30} , P_{0-45} , P_{0-60} , P_{10-30} , P_{10-45} , P_{10-60} , P_{20-30} , P_{20-45} and P_{30-30} treatments, however it was found at par with P_{20-60} , P_{30-45} , P_{30-60} , P_{40-30} , P_{40-45} treatments [3, 22, 27].

3.3.4 Uptake of Nitrogen by Maize

The Nitrogen, phosphorus and Potassium uptake of maize was remarkably influenced by the application of phosphorus through its direct, residual and cumulative effect (Table 4).

3.3.4.1 Direct effect

The maize crop recorded significantly higher uptake ($kg\ ha^{-1}$) of nitrogen due to application of 60 kg P_2O_5 ha^{-1} (110.30) compared to 45 kg P_2O_5 ha^{-1} (102.70) and 30 kg P_2O_5 ha^{-1} (92.34) during the first year [1,19,20]. Similarly during second year also the uptake ($kg\ ha^{-1}$) with 60 kg P_2O_5 ha^{-1} was greater (103.48) over 45 kg P_2O_5 ha^{-1} (96.15) and 30 kg P_2O_5 ha^{-1} (87.26).

3.3.4.2 Residual effect

The residual effect of 40 kg P_2O_5 ha^{-1} to rice showed significantly higher uptake ($kg\ ha^{-1}$) of nitrogen (110.03 and 101.96) over rest of the treatments during both the years [3, 22, 27]; however it was on par to 30 kg P_2O_5 ha^{-1} (66.72: 69.86).

3.3.4.3 Cumulative effect

Application of recommended Phosphorus to both the crops in the system through P_{40-60} treatment showed significantly higher uptake of nitrogen over rest of the treatment combinations during both years of the study [3, 22, 27and 27].

3.3.5 Phosphorus uptake by maize

3.3.5.1 Direct effect

The uptake of phosphorus ($kg\ ha^{-1}$) was significantly higher with direct application of 60 kg P_2O_5 ha^{-1} (18.13 and 17.30) compared to 45 kg P_2O_5 ha^{-1} (16.99 and 14.85) and 30 kg P_2O_5 ha^{-1} (15.64 and 13.29) respectively; during first and second years of the study. These findings corroborate the findings of other researchers [19, 20].

3.3.5.2 Residual effect

The residual effect of Phosphorus on phosphorus uptake ($kg\ ha^{-1}$) of maize showed highest uptake with 40 kg P_2O_5 ha^{-1} (18.72 in first year and 17.18 in second year) when compared to the lower phosphorus levels [1, 26, 33and 33].

Table 4: Effect of phosphorus levels in rice-maize cropping system on uptake ($Kg\ ha^{-1}$) of Nitrogen, phosphorus and potassium at harvest of maize.

Treatments	Nitrogen		Phosphorus		Potassium	
	First Year	Second Year	First Year	Second Year	First Year	Second Year
Direct (Rabi)						
P ₁ : 30 kg P_2O_5 ha^{-1}	92.34	87.26	15.64	13.29	58.96	60.44
P ₂ : 45 kg P_2O_5 ha^{-1}	102.70	96.15	16.99	14.85	65.33	68.30
P ₃ : 60 kg P_2O_5 ha^{-1}	110.30	103.48	18.13	17.30	69.28	73.75
S.Em.±	0.56	0.67	0.10	0.10	0.37	0.45
C.D.(P = 0.05)	1.63	1.94	0.28	0.30	1.07	1.31
Residual (Kharif)						
F ₁ :No Phosphorus	94.70	89.42	15.35	13.26	61.69	63.65
F ₂ : 10 kg P_2O_5 ha^{-1}	98.08	92.76	16.30	14.09	63.02	65.87
F ₃ : 20 kg P_2O_5 ha^{-1}	100.38	94.41	16.65	14.72	63.41	66.96
F ₄ : 30 kg P_2O_5 ha^{-1}	105.73	99.62	17.58	16.49	66.72	69.86
F ₅ : 40 kg P_2O_5 ha^{-1}	110.03	101.96	18.72	17.18	67.79	71.15

SE(m) ±	0.73	0.87	0.12	0.13	0.48	0.58
C.D.(P = 0.05)	2.10	2.51	0.36	0.39	1.38	1.69
Phosphorus levels to rice and maize						
P ₀₋₃₀	82.18	76.32	13.40	10.88	53.86	53.24
P ₀₋₄₅	96.95	92.13	15.80	13.56	63.01	66.24
P ₀₋₆₀	104.96	99.80	16.85	15.33	68.19	71.46
P ₁₀₋₃₀	88.57	83.77	14.90	12.13	56.24	58.75
P ₁₀₋₄₅	99.47	93.37	16.30	13.87	64.59	67.61
P ₁₀₋₆₀	106.20	101.14	17.69	16.28	68.22	71.26
P ₂₀₋₃₀	90.01	86.01	15.21	13.01	58.25	60.39
P ₂₀₋₄₅	101.32	95.09	16.92	14.43	63.88	67.38
P ₂₀₋₆₀	109.82	102.14	17.82	16.71	68.08	73.11
P ₃₀₋₃₀	98.94	94.31	16.59	15.01	63.04	64.64
P ₃₀₋₄₅	105.19	99.28	17.46	16.10	66.65	69.85
P ₃₀₋₆₀	113.05	105.26	18.67	18.36	70.47	75.08
P ₄₀₋₃₀	102.01	95.92	18.10	15.43	63.40	65.19
P ₄₀₋₄₅	110.59	100.90	18.48	16.28	68.52	70.42
P ₄₀₋₆₀	117.49	109.06	19.59	19.83	71.45	77.85
SE(m) ±	1.26	1.50	0.21	0.23	0.82	1.01
C.D.(P = 0.05)	3.65	4.35	0.62	0.67	2.39	2.93

3.3.5.3 Cumulative effect

These uptake values due to interaction effect of through P₄₀₋₆₀ treatment were significantly higher over other treatment combinations during both years [1, 26, 33 and 33].

3.4 Post-harvest available nutrients status

Perusal of data from table 5 revealed that soil available Nitrogen, Phosphorus and Potassium after harvest of maize crop was significantly influenced by different phosphorus management strategies in rice-maize cropping system.

3.4.1 Direct effect

Significantly lowest amount of available soil Nitrogen was recorded with 60 kg P₂O₅ ha⁻¹ compared to 45 and 30 kg P₂O₅ ha⁻¹, the differences in available soil Nitrogen between latter two were also significant. Similar trend was noticed with regard to available potassium in both the years except to available Phosphorus, which followed reverse trend [1, 19, 20, 33, 26 and 26].

Table 5: Direct, residual and cumulative effect of phosphorus levels in rice-maize cropping system on available Nitrogen, phosphorus and potassium (kg ha⁻¹) at the end of the 2nd year sequence.

Treatments	Nitrogen (kg ha ⁻¹)	Phosphorus (kg ha ⁻¹)	Potassium (kg ha ⁻¹)
Direct (Rabi)			
P ₁ : 30 kg P ₂ O ₅ ha ⁻¹	178.1	15.70	180.9
P ₂ : 45 kg P ₂ O ₅ ha ⁻¹	172.7	15.99	177.0
P ₃ : 60 kg P ₂ O ₅ ha ⁻¹	170.4	16.51	174.1
S.Em.±	0.6	0.03	0.5
C.D.(P = 0.05)	1.4	0.10	1.6
Residual (Kharif)			
F ₁ :No Phosphorus	180.0	15.47	181.8
F ₂ : 10 kg P ₂ O ₅ ha ⁻¹	177.2	15.68	178.9
F ₃ : 20 kg P ₂ O ₅ ha ⁻¹	174.5	16.03	177.9
F ₄ : 30 kg P ₂ O ₅ ha ⁻¹	168.8	16.38	174.7
F ₅ : 40 kg P ₂ O ₅ ha ⁻¹	168.2	16.78	173.4

SE(m) ±	0.6	0.04	0.7
C.D.(P = 0.05)	2.0	0.13	2.0
Phosphorus levels to rice and maize			
P ₀₋₃₀	186.1	15.16	185.8
P ₀₋₄₅	177.7	15.31	180.9
P ₀₋₆₀	176.2	15.95	178.7
P ₁₀₋₃₀	183.4	15.43	182.3
P ₁₀₋₄₅	174.6	15.59	178.4
P ₁₀₋₆₀	173.8	16.02	176.0
P ₂₀₋₃₀	180.5	15.62	181.2
P ₂₀₋₄₅	172.6	16.11	177.3
P ₂₀₋₆₀	170.4	16.35	175.2
P ₃₀₋₃₀	170.4	15.84	177.8
P ₃₀₋₄₅	169.5	16.28	175.3
P ₃₀₋₆₀	166.3	17.02	171.1
P ₄₀₋₃₀	170.2	16.44	177.5
P ₄₀₋₄₅	169.1	16.68	173.2
P ₄₀₋₆₀	165.4	17.23	169.5
SE(m) ±	1.1	0.08	1.2
C.D.(P = 0.05)	3.3	0.22	3.5

3.4.2 The residual effect

The residual effect of preceding season applied 40 and 30 kg P₂O₅ ha⁻¹ to rice had a diminishing effect on available nitrogen and potassium in soil compared to lower phosphorus levels. However the trend was reverse in case of soil available phosphorus, where significantly highest amount of soil available Phosphorus was recorded with 40 kg P₂O₅ ha⁻¹, which was followed by 30, 20 and 10 kg P₂O₅ ha⁻¹ and no phosphorus. The differences between any two of the Phosphorus levels were also significant [5, 27, 33 and 33].

3.4.3 Cumulative effect

The interaction effect of phosphorus applied to rice and maize had a significant effect on available soil nutrient status at the end of each dry season. The treatment combination P₄₀₋₆₀ to rice and maize recorded significantly lowest amount of soil available nitrogen and potassium compared to all other treatment combinations except to P₃₀₋₆₀. In contrast, P₄₀₋₆₀ treatment recorded greater available soil phosphorus values over all other treatment combinations, except P₃₀₋₆₀ [1, 19, 20, 33 and 26].

4. CONCLUSION

Higher performance of rice and maize crops was achieved with sustainable phosphorus application @ 30 kg P₂O₅ ha⁻¹ to rice and 60 kg P₂O₅ ha⁻¹ to maize in rice-zero till maize crop sequence with a saving of 10 kg P₂O₅ ha⁻¹.

REFERENCES

1. Arya KC, Singh SN. Productivity of maize (*Zea mays* L.) as influenced by different levels of Phosphorus, Zinc and irrigation. Indian Journal of Agricultural Sciences. 2001;71(1):57-59.

2. Buresh RJ, Pampolino, MF, Witt C. Field-specific potassium and phosphorus balances and fertilizer requirements for irrigated rice-based cropping systems. *Plant and Soil*. 2010;335: 35–64.
3. Chaudary SK, Thakur RB. Rational use of Phosphorus in Rice-wheat cropping system in Bihar Plains. *Oryza*. 2007;44(3):282-284.
4. Dobermann A, Cassman KG, Mamaril CP, Sheehy JE. . Management of phosphorus, potassium, and sulfur in intensive, irrigated lowland rice. *Field Crops Research* 1998;56 (1-2):113-138.
5. Gill HS, Meelu OP. Studies on the utilization of Phosphorus and causes for its differential response in rice-wheat rotation. *Plant and Soil*. 1983;74:211-222.
6. Gonsikar CP, Shinde VS. Nutrient management practices in crops and cropping systems. Scientific Publishers, Jodhpur, India; 1997.
7. Guignard, MS, Leitch AR, Acquisti C, Eizaguirre C, Elser JJ, Hessen DO, et al. Impacts of nitrogen and phosphorus: from genomes to natural ecosystems and agriculture. *Front. Ecol. Evol*. 2017;5-70.
8. Gupta RK, Singh Y, Ladha J K, Singh B, Singh J, Singh G, et al. Yield and Phosphorus Transformations in a Rice–Wheat System with Crop Residue and Phosphorus Management. *Soil Science Society of America Journal* 2007;71(5):1500–1507.
9. Jackson ML. *Soil Chemical Analysis*. Prentice hall of India private limited, New Delhi; 1973.
10. Jackson ML. *Soil Chemical Analysis–Advanced Course*, 2nd edition. Author's publication. University of Wisconsin, Madison, USA;1979.
11. Khan A, Lu G, Ayaz M, Zhang H, Wang R, Lv F, et al. Phosphorus efficiency, soil phosphorus dynamics and critical phosphorus level under long-term fertilization for single and double cropping systems. *Agric. Ecosyst. Environ*. 2018; 256:1–11.
12. Lal R. Soil carbon sequestration to mitigate climate change. *Geoderma*. 2004;123:1–22.
13. Masthan SC. Production potential and economic evaluation of rice based cropping systems as influenced by levels of phosphorus. *Oryza*. 2000;37(2):24-26.
14. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soil by extraction with bicarbonate. Circular, U S Department of Agriculture 1954; 939.
15. Panse, UG, Sukhatme PV. *Statistical Methods for Agricultural Workers*. ICAR, New Delhi, 1985;100–174.
16. Pheav S, Bell RW, White PF and Kirk GJD. Fate of applied Fertilizer Phosphorus in highly weathered sandy soil under lowland rice cropping and its residual effect. *Field Crops Research*. 2003; 81:1–16.
17. Piper CS. *Soil and Plant Analysis*. Inter Science Publishers, New York, 1966;59.
18. Ponnampetuma FN. The chemistry of submerged soils. *Advances in Agronomy*. 1972; 24:29–96.
19. Ramesh Ch, Venkata Ramana M, Jaya Sree G, Srinivasa Raju M, Siva Sankar A.. Performance of rice fallow zero till maize (*Zea mays* L.) to levels of phosphorus and its time of application. *The Pharma Innovation Journal*. 2021;10(12):1875-1880.
20. Ramesh Ch, Venkata Ramana M, Jaya Sree G. Effect of Different Rates and Time of Application of Phosphorus on Yield, Soil Fertility, Nutrient Uptake and Monetary Returns of No-till Maize (*Zea mays* L.) after Lowland Rice. *International Journal of Economic Plants*. 2022;9(4):349-358.
21. Roberts TL, Johnston AE. Phosphorus use efficiency and management in agriculture. *Resources, Conservation, Recycling*. 2015;105: 275–281.
22. Sagger S, Meelu OP, Dev G. Effect of Phosphorus applied in different phases in rice-wheat rotation. *Indian Journal of Agronomy*. 1985;30(2):199-206.

- 23.Sah RN, Mikkelsen DS. Transformation of inorganic phosphorus during the flooding and draining cycles of soil. Soil Science Society of America Journal. 1986;50:62–67.
- 24.Saleque MA, Kirk GJD. Root-induced solubilization of phosphate in the rhizosphere of lowland rice. New Phytol. 1995;129: 325–336.
- 25.Sanyal SK, De Datta SK. Chemistry of phosphorus transformations in soil. Advances in Soil Science 1991;16:1–120.
26. Sharma AR, Mitra BN. Effect of N and P on rice and their residual effect on succeeding wheat/gram crop. Indian Journal of Agronomy. 1989; 34(1):40-44.
- 27.Singh Y, Dobermann A, Singh B, Bronson KF, Khind CS. Optimal Phosphorus Management Strategies for Wheat–Rice Cropping on a Loamy Sand. Soil Science Society of America Journal. 2000;64:1413–1422.
28. Subbaiah BV, Asija GL. A rapid procedure for the determination of available nitrogen in soils. Current Science. 1956; 25:259 – 260.
- 29.Timsina J, Connor DJ. Productivity and Management of Rice-Wheat Cropping Systems: Issues and Challenges. Field Crops Research. 2001;69: 93-132.
- 30.Timsina J, Jat ML, Majumdar K. Rice-maize systems of South Asia: Current status, future prospects and research priorities for nutrient management. Plant and soil. 2010; 335 (1-2):65-82.
- 31.Walkley A, Black CA. Estimation of soil organic carbon by the Chromic acid titration method. Journal of Soil Science. 1934; 37: 28 – 29.
- 32.Willett IR, Chartres CJ, Nguyen TT. Migration of phosphate into aggregated particles of ferrihydrite. Journal of Soil Science. 1988;39: 275–282.
- 33.Yadav RL, Yadav DS, Singh RM Kumar A. Long term effects of inorganic fertilizer inputs on crop productivity in a rice-wheat cropping system. Nutrient Cycling in Agro ecosystems. 1998; 51:193-200.