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

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Authors' contributions

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

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ABSTRACT

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

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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 [1]. 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 [2]. 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 [3-5]. Scheduling fertilizer to cropping systems rather than single crop basis help its efficient application and economizing expenses [6-8]. 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 [9]. 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 [10-14]. 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 [9].

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 [9] and [15]. 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 [16]. Efficient utilization of nutrient Phosphorus, residual and cumulative effects of Phosphorus should be deliberated while framing fertilizer use recommendations in diverse cropping sequences [15].

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. MATERIALS AND METHODS

The study was conducted in the College farm situated at College of Agriculture, Rajendranagar, Hyderabad, Telangana, India (17^0 19' North latitude, 78^0 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 100 g 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 [18], 8.33 pH [19], 0.46 dSm^{-1} electrical conductivity [19], 197.50 kg ha^{-1} available Nitrogen [20], 16.96 kg ha^{-1} available Phosphorus [21] and 163.5 kg ha^{-1} available Potassium [22]. 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; F_1: No Phosphorus, F_2: 10 kg P_2O_5 ha^{-1}, F_3: 20 kg P_2O_5 ha^{-1}, F_4: 30 kg P_2O_5 ha^{-1} and F_5: 40 kg P_2O_5 ha^{-1} and three phosphorus levels to maize namely; P_1: 30 kg P_2O_5 ha^{-1}, P_2: 45 kg P_2O_5 ha^{-1} and P_3: 60 kg P_2O_5 ha^{-1}. The P_2O_5 (kg ha^{-1}) levels applied to rice and zero tillage maize respectively in different treatments were (T_1: P_{0-30}, T_2:P_{0-45}, T_3: P_{0-60}, T_4: P_{10-30}, T_5: P_{10-45}, T_6: P_{10-60}, T_7: P_{20-30}, T_8: P_{20-45}, T_9: P_{20-60}, T_{10}: P_{30-30}, T_{11}: P_{30-45}, T_{12}: P_{30-60}, T_{13}: P_{40-30}, T_{14}: P_{40-45} and T_{15}: P_{40-60}).

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 900 M) 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 P_2O_5 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 m^2 area in rice and 10.56 m^2 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 [21] and was expressed as kg of Phosphorus ha^{-1} after adjusting for bulk density.

2.1 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 [23]. 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 P_2O_5 ha^{-1} to rice with an increment of 10 kg P_2O_5 ha^{-1} significantly increased the grain yield of rice up 20 kg P_2O_5 ha^{-1}; the increased Phosphorus beyond this level did not increase the grain yield significantly. Application of 60 kg P_2O_5 ha^{-1} gave a grain yield of 5341 and 5113 kg ha^{-1} respectively in first and second years, followed by 30 kg P_2O_5 ha^{-1} (5253 and 5082 kg ha^{-1}), 20 kg P_2O_5 ha^{-1} (5240 and 5008 kg ha^{-1}), 10 kg P_2O_5 ha^{-1} (4835 and 4686 kg ha^{-1}) and no phosphorus (4462 and 4548 kg ha^{-1}) treatment [24-26].

3.1.2 Direct effect on rice straw yield

The increase in P level to rice from 0 to 40 kg P_2O_5 ha^{-1} significantly increased the straw yield of rice up to 20 kg P_2O_5 ha^{-1} in both the years. Direct application of 20 kg P_2O_5 ha^{-1} to rice recorded significantly higher straw yield (5829 and 5825 kg ha^{-1}) over 10 kg P_2O_5 ha^{-1} and no phosphorus in first and second years, respectively, however it did not differ significantly with 30 and 40 kg P_2O_5 ha^{-1} in both years. These results corroborate the findings of many researchers [24,27,25,28,26].

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 [25,28,26]. Application of 60 kg P_2O_5 ha^{-1} to maize during first year produced significantly higher grain yield of rice (5034 kg ha^{-1}) over 45 kg P_2O_5 ha^{-1} (4899 kg ha^{-1}) and 30 kg P_2O_5 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 [24,28,26]. Application of 60 kg P_2O_5 ha^{-1} to maize in first year produced significantly higher straw yield of rice (5795 kg ha^{-1}) over 45 kg P_2O_5 ha^{-1} (5683 kg ha^{-1}) and 30 kg P_2O_5 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 P_2O_5 ha^{-1} to rice through P_{20-60} treatment resulted in higher grain yield of rice over application of 10 kg P_2O_5 ha^{-1} (P_{10-30} and P_{10-45}) and no phosphorus treatment (P_{0-30} and P_{0-45} and P_{0-60}). However, it was found on par to that of application of 30 kg P_2O_5 ha^{-1} ($P_{30-30,}$ P_{30-45} and P_{30-60}) and 40 kg P_2O_5 ha^{-1} ($P_{40-30,}$ P_{40-45} and P_{40-60}) to rice [24,27,25,28,26]. 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 [29,25,11,13,30] besides, root-induced solubilization of acid soluble Phosphorus by rice [12]. 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 [15].

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 P_2O_5 ha^{-1} to rice through P_{20-60} treatment resulted in higher straw yield of rice over application of 10 kg P_2O_5 ha^{-1} ($P_{10-30,}$ P_{10-45} and P_{10-60}) and no phosphorus treatment (P_{0-30}, P_{0-45} and $P_{0-60)}$. However, it was found on par to that of application of 30 kg P_2O_5 ha^{-1} (P_{30-30}, P_{30-45} and P_{30-60}) and 40 kg P_2O_5 ha^{-1} (P_{40-30}, P_{40-45} and P_{40-60}) to rice in rice-maize sequence. Similar findings were also reported by many researchers [15,6,25,26,31].

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 P_2O_5 ha^{-1} to 4830 and 4836 kg ha^{-1} by the application of 45 kg P_2O_5 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 P_2O_5 ha^{-1} in the corresponding years [7,8].

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 P_2O_5 ha^{-1} to 6988 and 6816 kg ha^{-1} by the application of 45 kg P_2O_5 ha^{-1} and to 7324 and 7234 kg ha^{-1} by application of 60 kg P_2O_5 ha^{-1} in two years, respectively. These findings confirm the findings of other researchers [7,8].

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_2O_5 ha^{-1}	4835	4686	5545	5440
F_3: 20 kg P_2O_5 ha^{-1}	5240	5008	5829	5825
F_4: 30 kg P_2O_5 ha^{-1}	5253	5082	5867	5893
F_5: 40 kg P_2O_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_2O_5 ha^{-1}	-	4730	-	5562
P_2: 45 kg P_2O_5 ha^{-1}	-	4899	-	5683
P_3: 60 kg P_2O_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

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_2O_5 ha^{-1}	4436	4447	6469	6272
P_2: 45 kg P_2O_5 ha^{-1}	4830	4836	6988	6816
P_3: 60 kg P_2O_5 ha^{-1}	5144	5198	7324	7234
S.Em.±	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_2O_5 ha^{-1}	4692	4711	6817	6691
F_3: 20 kg P_2O_5 ha^{-1}	4706	4726	6849	6744
F_4: 30 kg P_2O_5 ha^{-1}	4937	5032	7063	6922
F_5: 40 kg P_2O_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
C.D.(P = 0.05)	210	267	295	314

3.2.3 Residual effect on maize grain yield

The residual effect of phosphorus applied at 30 kg P_2O_5 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 P_2O_5 ha^{-1} was found on par [32,28,31].

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 P_2O_5 ha^{-1}, there after the increase was not significant in both years [32,28,31].

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 P_{40-60} treatment. Nevertheless, P_{40-60} was found at par with P_{30-60} (5210 and 5270 kg ha^{-1}) and resulted in significantly higher grain yield over rest of the treatment combinations [32,10,16,26].

3.2.6 Cumulative effect on maize stover yield

The treatment P_{40-60} being on par with P_{30-60} (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 [15,33,30] 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 [32,10,16,26].

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 P_2O_5 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 P_2O_5 ha^{-1}, however it was found on par with 30 and 40 kg P_2O_5 ha^{-1}; except to the first year, which was significantly lower to 30 and 40 kg P_2O_5 ha^{-1}. The differences in uptake of Nitrogen between 0 and 10 kg P_2O_5 ha^{-1} were also significant [24,25,26].

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 P_2O_5 ha^{-1} to maize showed significantly higher uptake of 95.30 kg ha^{-1} over 45 and 30 kg P_2O_5 ha^{-1} [24,25,26].

3.3.1.3 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 significantly increased the uptake of nitrogen by rice over the treatments of P_{0-30}, P_{0-45}, P_{0-60}, P_{10-30}, P_{10-45} and P_{10-60}; however it was found at par with rest of the treatments ($P_{20-30,}$ $P_{20-45,}$ $P_{20-60,}$ $P_{30-30,}$ $P_{30-45,}$ $P_{30-60,}$ $P_{40-30,}$ P_{40-45}).

3.3.2 Uptake of Phosphorus by rice

3.3.2.1 Direct effect

Application of 40 kg P_2O_5 ha^{-1} to rice recorded significantly higher uptake 21.53 kg ha^{-1} over lower phosphorus levels [24,25,26] during the first year. While in second year 30 kg P_2O_5 ha^{-1} recorded significantly higher uptake 19.39 kg ha^{-1} over lower phosphorus levels; however it was found at par with 40 kg P_2O_5 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 P_2O_5 ha^{-1} to maize resulted in significantly higher uptake (19.63 kg ha^{-1}) over 45 and 30 kg P_2O_5 ha^{-1} [24,25,26].

3.3.2.3 Cumulative effect

The interaction of 'Phosphorus' levels in rice and maize during second year showed that application of 40 kg P_2O_5 ha^{-1} to rice through P_{40-60} treatment showed significantly higher phosphorus uptake by rice over rest of the treatments; however it was found at a par with P_{40-30}, P_{40-45} and P_{30-60}. The greater nutrient uptake values with higher levels of phosphorus were due to higher grain and straw yields. These results confirm the findings of [24,15,10,25].

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 P_2O_5 ha^{-1} to rice recorded higher uptake (88.71 and 77.86 kg ha^{-1}) compared to no Phosphorus, 10 and 20 kg P_2O_5 ha^{-1} in first and second years, respectively. Application of 20 kg P_2O_5 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 P_2O_5 ha^{-1}, 10 kg P_2O_5 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 [24,25,26].

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 [24,25,26].

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 [32,7,8]. 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 [24,25,26]; however it was on par to 30 kg P_2O_5 ha^{-1} (66.72 and 69.86).

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_2O_5 ha^{-1}	83.67	88.14	18.05	17.48	81.73	69.99
F_3: 20 kg P_2O_5 ha^{-1}	91.81	95.34	20.05	19.04	87.55	76.78
F_4: 30 kg P_2O_5 ha^{-1}	92.99	96.22	20.77	19.39	88.71	77.86
F_5: 40 kg P_2O_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_2O_5 ha^{-1}	-	89.54	-	16.93	-	72.25
P_2: 45 kg P_2O_5 ha^{-1}	-	92.45	-	18.83	-	74.27
P_3: 60 kg P_2O_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

3.3.4.3 Cumulative effect

Application of recommended Phosphorus to both the crops in the system through $P_{40\text{-}60}$ treatment showed significantly higher uptake of nitrogen over rest of the treatment combinations during both years of the study [3], [22] and [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 [7] and [8].

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 [32,28,31].

3.3.5.3 Cumulative effect

These uptake values due to interaction effect of through $P_{40\text{-}60}$ treatment were significantly higher over other treatment combinations during both years [32,28,31].

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						
$P_{0\text{-}30}$	82.18	76.32	13.40	10.88	53.86	53.24
$P_{0\text{-}45}$	96.95	92.13	15.80	13.56	63.01	66.24
$P_{0\text{-}60}$	104.96	99.80	16.85	15.33	68.19	71.46
$P_{10\text{-}30}$	88.57	83.77	14.90	12.13	56.24	58.75
$P_{10\text{-}45}$	99.47	93.37	16.30	13.87	64.59	67.61
$P_{10\text{-}60}$	106.20	101.14	17.69	16.28	68.22	71.26
$P_{20\text{-}30}$	90.01	86.01	15.21	13.01	58.25	60.39
$P_{20\text{-}45}$	101.32	95.09	16.92	14.43	63.88	67.38
$P_{20\text{-}60}$	109.82	102.14	17.82	16.71	68.08	73.11
$P_{30\text{-}30}$	98.94	94.31	16.59	15.01	63.04	64.64
$P_{30\text{-}45}$	105.19	99.28	17.46	16.10	66.65	69.85
$P_{30\text{-}60}$	113.05	105.26	18.67	18.36	70.47	75.08
$P_{40\text{-}30}$	102.01	95.92	18.10	15.43	63.40	65.19
$P_{40\text{-}45}$	110.59	100.90	18.48	16.28	68.52	70.42
$P_{40\text{-}60}$	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

3.4 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 P_2O_5 ha^{-1} compared to 45 and 30 kg P_2O_5 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 [32,7,8,31,28].

3.4.2 The residual effect

The residual effect of preceding season applied 40 and 30 kg P_2O_5 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 P_2O_5 ha^{-1}, which was followed by 30, 20 and 10 kg P_2O_5 ha^{-1} and no phosphorus. The differences between any two of the Phosphorus levels were also significant [15,26,31].

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 2^{nd} year sequence.

Treatments	Nitrogen (kg ha^{-1})	Phosphorus (kg ha^{-1})	Potassium (kg ha^{-1})
Direct (*Rabi*)			
P_1: 30 kg P_2O_5 ha^{-1}	178.1	15.70	180.9
P_2: 45 kg P_2O_5 ha^{-1}	172.7	15.99	177.0
P_3: 60 kg P_2O_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_2O_5 ha^{-1}	177.2	15.68	178.9
F_3: 20 kg P_2O_5 ha^{-1}	174.5	16.03	177.9
F_4: 30 kg P_2O_5 ha^{-1}	168.8	16.38	174.7
F_5: 40 kg P_2O_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

3.4.3 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 P_{40-60} to rice and maize recorded significantly lowest amount of soil available nitrogen and potassium compared to all other treatment combinations except to P_{30-60}, In contrast, P_{40-60} treatment recorded greater available soil phosphorus values over all other treatment combinations, except P_{30-60} [32,7,8,31,28].

4. CONCLUSION

Higher performance of rice and maize crops was achieved with sustainable phosphorus application @ 30 kg P_2O_5 ha^{-1} to rice and 60 kg P_2O_5 ha^{-1} to maize in rice-zero till maize crop sequence with a saving of 10 kg P_2O_5 ha^{-1}.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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