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Effect of Phosphorous Application on Uptake, Yield and Fertilizer Use Efficiency under Rice-Rice and Rice-Sunflower Systems in High P Soils

A. Srinivas, P.Surendra Babu, A.Madhavi, G.E.C.H.Vidyasagar and G.R. Maruthi Sankar*

Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad–500030, Telangana, India
**World Bank-Sujala Project, Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, GKVK, Bangalore-560065, Karnataka, India.*

Field experiments on high P soils were conducted during 2009-10 and 2010-11 to assess (i) P fertilizer requirement and (ii) P fertilizer use efficiency using ^{32}P isotope in rice–rice and rice–sunflower (*rabi*) systems. Four treatments in *kharif* (T1: 100%, T2: 75%, T3: 50% and T4: 25%) recommended dose of phosphorus (RDP) and three treatments in *rabi* (T1: 100%, T2: 75%, T3: 50% RDP) were tested. A uniform dose of 100% recommended 48 kg ha^{-1} of N and 24 kg ha^{-1} of K were applied along with P treatments. The P removal both grain and straw by both crops under rice-rice system was at par with 100 and 75% RDP. The percent P utilization in entire system revealed that 75% RDP gave better utilization of applied P to a tune of 26% compared to 22% realized by 100% RDP in each crop. Similar trend of P removal by rice and sunflower seeds in rice-sunflower system was observed. Percent P utilization in both crops was 24.5% under 100% RDP and 27.2% under 75% RDP. The study clearly indicated 25% reduction in P fertilization for both cropping systems in high P soils.

Keywords: Fertilizer P, ^{32}P isotope, P uptake, fertilizer use efficiency, rice-rice, rice-sunflower

Introduction

The importance of phosphorus fertilizers in crop production is undisputable. Concerted efforts were made to enhance the use efficiency of not only P but also of other costly nutrient inputs to economize cost of cultivation and conserve resources. Phosphatic fertilizers are known to be highly reactive with the soil and get fixed in upper layers with efficiency never exceeding beyond 20 to 25%. The continuous or indiscriminate use of P fertilizer would increase P accumulation in top layers of soils. The accumulation of P in soils would be a continuous phenomenon as long as fertilizers are used. Deb (2009) indicated that unless P-fixing sites are saturated to certain degree, availability of native and applied P will not increase. Therefore, extent of P-accumulation is also important to realize its implications. The occurrence of high P soil will have implication of (a) saving P fertilizer without sacrificing current level of production; and (b) interference with availability of other nutrients in soil. Singh *et al*., (1996) reported that sunflower seed yield increased due to application of 80 mg P. In medium P soils, Rao *et al.,* (1989) tried different P levels in rice-based system. They reported that rice yield increased due to residual effects at 80 and 120 kg P_2O_5 ha^{-1}.

Choudhary and Thakur (2007) observed that P dose could be skipped in either of any crop or reduced to 50% under rice-wheat sequence. However, it was better to skip P application in rice wet season than wheat dry season as well as nutrient uptake point of view. Patel *et al.,* (2012) reported that rice responded significantly to P application with respect to grain yield. The uptake of P by rice and P in soils after rice harvest was recorded higher if P application was made through press-mud biocompost compared to single super phosphate (SSP). Application of P to rice significantly increased millable cane yield and sugarcane equivalent of rice–sugarcane, total P uptake by sugarcane and P status of

*Corresponding Author Email: gmsankar2009@gmail.com

soils after harvest of sugarcane. Application of 40 kg P_2O_5 ha^{-1} produced 858 kg ha^{-1} yield of cowpea, which was 24.2 and 9.8% higher over control and 20 kg P_2O_5 ha^{-1} respectively (Jat *et al*., 2013).

Wallace *et al.,* (1977) studied influence of P on zinc, iron, manganese and copper uptake and found that at high pH, increasing solution P decreased leaf, stem, and root concentration of Zn, Mn and Cu in soybean. They observed a decrease in iron content of roots but not in leaves and stem, while in contrast at low pH, increased P resulted in more Zn, Mn and Cu but less Fe in leaves, stem, and roots of soybean. Agrawal and Verma (1998) observed an increase in P content (0.33 %) and uptake (18.5 kg ha^{-1}) by sunflower up to 90 kg P_2O_5 application. Gill *et al*., (2004) reported that P @ 100 mg kg^{-1} significantly increased P in *Brassica* and sunflower. Bogdanovic *et al.,* (1999) concluded that a high soil P reduced Zn availability. The content of Zn in stalks and leaves was significantly lower in treatments of P than control due to P x Zn interaction.

Highest grain yield of cowpea was obtained with 20 and 5 kg Zn ha^{-1}, while haulm occurred at P @ 60 kg and Zn @ 2.5 kg ha^{-1} (Oseni 2009). Higher P availability in soil significantly decreased Mn, Zn and Cu in eight barley cultivars. Total zinc uptake by root plus shoot decreased sharply when Olsen P at harvest was >15 mg P kg^{-1} soil (Manchanda *et al*. 2012). The present investigation was taken up to study: (i) P fertilizer requirement to rice–rice and rice–sunflower systems; and (ii) P fertilizer use efficiency using ^{32}P isotope in rice–rice and rice–sunflower systems on a high P soil.

Materials and Methods

The present study was conducted in Hyderabad located at 18° 95' and 77° 85' and at an altitude of 542.6 m above mean sea level. Hyderabad falls under semi-arid climate with mean annual rainfall of 800 mm. The soils of experimental plots of high available P were collected prior to the selection of site for experimentation. Standard methods were followed for preparing soil samples for analysis.

The experimental area was divided into 2 fields and designated as Field–I and Field–II. Each field was further divided into two parts and designated as Plot–1 and Plot–2 in Field-I and Plot-3 and Plot-4 in Field-II. Plot-1 of field-1 was used for rice-rice and plot-2 was used for rice-sunflower cropping system during 2009-10. Thus during 2009-10, rice was raised in plot-1 and plot-2 in *kharif*, whereas rice was raised in plot-1 and sunflower was raised in plot-2 in *rabi*.

During 2010-11, Field–II was used to repeat the experiment of rice–rice and rice–sunflower system as a second year study in plot-3 and plot-4. Four treatments in *kharif* (T1: 100%, T2: 75%, T3: 50% and T4: 25% RDP) and three treatments in *rabi* (T1: 100%, T2: 75%, T3: 50% RDP) were tested. A uniform dose of 100% recommended 48 kg ha^{-1} of N and 24 kg ha^{-1} of K were applied along with P treatments. ^{32}P 0.25 mCi g^{-1} P_2O_5 was used to tag P during *kharif* and *rabi* crops. During *kharif*, standard micro-plots were made on one side of a treated plot and P^{32} was applied. During *rabi*, where *kharif* plot was divided into 3 sub-plots (to impose *rabi* P treatments), micro-plots in these sub-plots were made on opposite side of what has been done in *kharif*.

Each experimental plot had a net plot size of 13.2 m x 5.4 m in Field-1 during 2009-10 and Field-2 during 2010-11. Each plot included a micro-plot at south-west corner. Paddy seed (var. BPT-5204) was used for raising nursery after treating with carbendazim @ 3 g kg^{-1} seed. Recommended N, P and K for nursery was applied before sowing. Recommended N @ 120 kg ha^{-1}, P @ 60 kg ha^{-1}, K @ 40 kg ha^{-1} were applied in both *kharif* and *rabi* seasons, while zinc sulphate @ 50 kg ha^{-1} was applied only in *kharif* season. Nitrogen was applied in 3 equal splits at transplanting, tillering and panicle initiation stages, while P, K and Zinc Sulphate were applied as basal.

Irrigation was given to maintain 2 cm height water layer in the field. Two manual weedings were done at 25 and 45 days after transplanting. Required quantity of P fertilizer as per treatment in micro-plots for each season were calculated. Based on fertilizer quantity, ^{32}P isotope was obtained from Bhabha Atomic Research Center, Mumbai and was tagged physically by preparing P solution according to the treatments. In micro-plots, ^{32}P tagged P_2O_5 was applied one week after transplanting. Plant samples of ^{32}P tagged P_2O_5 applied in all micro-plots of rice were collected from each plot at maximum tillering stage. Plant samples of grain and straw at harvest were collected from each main plot from both fields. Post-harvest soil samples (0-15 cm depth) were collected to know the P status.

Cultivation details for rabi rice (in plot-1 of field-I and plot-3 of field-II)

In order to study the direct and residual effect of P in rice–rice system, rice was taken in Plot-1 of Field-I and Plot-3 of Field-II during 2009-10 and 2010-11 respectively. Each treated plot of *kharif* was manually worked out and divided into 3 equal parts and *rabi* treatments were imposed randomly in each plot. The micro plots were made on opposite side of the plot in contrast to earlier *kharif* micro plot. Recommended fertilizer dose and ^{32}P @ 0.25 mCi g^{-1} P_2O_5 were applied similar to *kharif*. The plants in micro-plots were sampled at maximum tillering stage and grain and straw samples were collected at the harvest stage.

Cultivation details for rabi sunflower (in plot-2 of field-I and plot-4 of field-II)

Sunflower (var. DRSF-108) was raised during *rabi* of 2009-10 and 2010-11 in Plot-2 of Field-I and Plot-4 of Field-II respectively after *kharif* rice. The field with different plots of *kharif* was prepared manually to achieve optimum tilth. Seed treatment with imidacloprid @ 5 g kg^{-1} and carbendazim 1 g kg^{-1} seed was done. Recommended doses of N @ 60 kg ha^{-1}, P @ 60 kg ha^{-1} and K @ 30 kg ha^{-1} were applied to all plots. P^{32} was applied in micro-plots at 20 DAS. The plots were maintained weed free during entire season. Irrigation was given at 15-20 days interval coinciding with critical stages (bud initiation, flowering and seed setting) of crop growth. Plant samples from micro-plots were collected at bud initiation stage. Sunflower seed and stalk samples were collected at harvest. Soil samples after harvest of *rabi* rice and sunflower were collected and analyzed for available P_2O_5.

Soil and plant analysis

The standard procedures of soil chemical analysis of pH, electrical conductivity (dS m^{-1}) were followed (Jackson, 1973). The organic carbon (%) by rapid titration method (Walkley and Black, 1934), available N (Subbaiah and Asija, 1956) and P was extracted by using Olsen's extractant (Olsen *et al.,* 1954). Available K was determined as discussed by Jackson (1973). Available Zn (mg kg^{-1}) was estimated by atomic absorption spectrophotometer employing the method given by Lindsay and Norvell (1978). Based on the analysis, the soil had a pH of 7.45, bulk density of 1.55 mg m^{-1} and electrical conductivity of 0.34 dsm^{-1}, organic carbon of 0.82%, N of 282 kg ha^{-1}, P_2O_5 of 126 kg ha^{-1}, K_2O of 302 kg ha^{-1} and DTPA - Zn of 3.1 mg kg^{-1}.

The oven dried plant samples were ground in Wiley mill and used for digestion as per the procedure given by Shaw (1959) using tri acid mixture of HNO_3: H_2SO_4: $HClO_4$ in 9:4:1 ratio for non-radio isotope tagged plant samples. For radio assay, analysis was carried out by following procedures given by IAEA (1976). One gram of powdered plant sample was weighed into silica crucible and charred on an electrical heater as pre-ignition treatment. Though, volatalization losses of P at high temperatures above 300 ºC was low, magnesium nitrate was added at various concentrations to reduce P losses. Later, it was ashed at 823^0 K in a muffle furnace for 2-3 hours. The contents of ash in crucibles were digested in 5 ml of 1:1 HNO_3 and heated gently on a sand bath. The contents were filtered using 1:10 HNO_3 and volume was made up to 25 ml. Phosphorus was determined by modified vanadomolybdo phosphoric acid yellow colour method (Jackson, 1973). One ml aliquot of above solution was pipetted into a 25 ml volumetric flask and colour was developed with Barton's reagent. The colour intensity was read on a Klett Summerson colorimeter using blue filter (470 nm). For radio assay, 5 ml of above aliquot was taken into small micro beakers and dried under infra red lamp. Using GM counter (Model RCS 4027A), ^{32}P activity of dried residue in micro beakers was counted along with fertilizer standards. The calculations for radio assaying were done as below:

$$\text{Specific activity (cpm/mg P)} = \frac{[\text{Counts in 5 ml of extractant}] \times [\text{ml required mg } P^{-1}]}{\text{Quantity of extractant} \times \text{time of counting (seconds)}}$$

$$\% \text{ Pdff} = \frac{\text{Specific activity in plant sample}}{\text{Specific activity in fertilizer}} \times 100$$

$$\text{Fertilizer P uptake (Kg ha}^{-1}) = \% \text{ Pdff} \times \text{Total P uptake}$$

$$\text{Soil P uptake (Kg ha}^{-1}) = \text{Total P uptake} - \text{fertilizer P uptake}$$

$$\text{P utilization (\%)} = \frac{\text{Fertilizer P uptake}}{\text{Quantity of P applied through fertilizer}} \times 100$$

The standard analysis of variance of Randomized Block Design was carried out to test the P fertilizer effects on different parameters in *kharif* and *rabi* seasons.

Results and Discussion

Rice-Rice system

Effect of P doses on nutrient content and uptake of P in kharif rice grain

The P content in *kharif* rice grain ranged from 0.33 to 0.35% in different treatments. Application of different levels of P fertilizer did not influence the P content of rice grain in individual years and also when pooled over years as given in table 1. The P-uptake by *kharif* rice grain was significantly influenced by different rates of P fertilizer. The mean P uptake decreased gradually from 19.97 to 17.40 kg ha^{-1} with a decrease in P doses. Application of 100 and 75% RDF were at par, while 25 and 50% RDP differed significantly in influencing the P uptake in rice grain.

Effect of P doses on content and uptake of zinc in kharif rice grain

The zinc content of rice grain ranged from 21.26 to 24.77 mg kg^{-1} as P dose increased from 25 to 100% RDP (Table 1). However, lower doses of P gave significantly lower zinc content in rice grain compared to 75 and 100% RDP**.** The main effect of years and interaction of years and treatments on zinc content in grain were not significant. The zinc uptake by *kharif* rice grain was significantly affected by different rates of P applied to the crop. The mean zinc uptake ranged from 112 to 141 g ha^{-1}. Reduced dose of P @ 50 and 25% RDP gave significantly lower zinc uptake by rice grain compared to 75 and 100% RDP.

Table 1. Effect of fertilizer P on content and uptake of P and zinc in *kharif rice* grain under rice–rice system

Treatments	2009	2010	Mean	2009	2010	Mean
P content (%)				Zinc content (mg kg^{-1})		
100% RDP	0.35	0.35	0.35	24.60	24.95	24.77
75% RDP	0.35	0.34	0.35	24.54	24.24	24.39
50% RDP	0.34	0.33	0.34	22.29	22.46	22.38
25% RDP	0.33	0.33	0.33	20.98	21.53	21.26
Mean	*0.34*	*0.34*		*23.10*	*23.29*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.013*	*0.012*	*0.024*	*0.34*	*0.48*	*0.68*
LSD (p < 0.05)	*NS*	*NS*	*NS*	*NS*	*1.40*	*NS*
P uptake (kg ha^{-1})				Zinc uptake (g ha^{-1})		
100% RDP	19.81	20.12	19.97	138	142	140
75% RDP	19.72	19.81	19.76	141	141	141
50% RDP	17.91	17.91	17.91	118	124	121
25% RDP	17.33	17.47	17.40	110	114	112
Mean	*18.69*	*18.82*		*127*	*130*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.35*	*0.48*	*0.71*	*2.05*	*2.89*	*4.09*
LSD (p < 0.05)	*NS*	*1.51*	*NS*	*NS*	*8.45*	*NS*

Y : Years T : Treatments SEm : Standard error of mean
NS : Not significantLSD : Least significant difference

Effect of P on nutrient content and uptake of P in kharif rice straw

The P content of *kharif* rice straw was not influenced due to different rates of P and interaction of years and treatments as given in Table 2. The P content was in the range of 0.13 to 0.15% under different treatments. The P uptake by *kharif* rice straw was significantly affected by different levels of P. P @ 75 and 100% RDP gave at par P uptake by rice straw but uptakes were significantly higher than that of 25 and 50% RDP.

Effect of P doses on content and uptake of zinc in kharif rice straw

The zinc content in *kharif* rice straw was significantly influenced by P doses. Application @ 25% RDP gave lowest zinc content of 24.97 mg kg^{-1} and was significantly lower than any other level of P. The zinc content of rice straw was at par due to application of 100 and 75% RDP. The zinc uptake was significantly influenced by different rates of P (Table 2). The mean zinc uptake ranged from 174 to 175 mg kg^{-1} with application of 75 and 100% RDP to the crop. Application of 50% RDP gave zinc uptake of 155 mg kg^{-1} in *kharif* rice straw which was significantly higher compared to 25% RDP and slightly lower than 75 and 100% RDP application.

Table 2. Effect of fertilizer P on content and uptake of P and zinc in *kharif* rice straw under rice–rice system

Treatments	2009	2010	Mean	2009	2010	Mean
P content (%)				Zinc content (mg kg^{-1})		
100% RDP	0.15	0.15	0.15	29.27	29.92	29.59
75% RDP	0.15	0.15	0.15	28.72	28.61	28.66
50% RDP	0.13	0.13	0.13	27.44	27.63	27.54
25% RDP	0.13	0.13	0.13	25.10	24.83	24.97
Mean	*0.14*	*0.14*		*27.63*	*27.75*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.004*	*0.006*	*0.008*	*0.50*	*0.71*	*1.00*
LSD (p < 0.05)	*NS*	*NS*	*NS*	*NS*	*2.04*	*NS*
P uptake (kg ha^{-1})				Zinc uptake (g ha^{-1})		
100% RDP	8.70	9.01	8.85	171	178	175
75% RDP	9.07	9.21	9.14	173	175	174
50% RDP	7.33	7.58	7.46	152	157	155
25% DP	6.88	7.02	6.95	131	132	132
Mean	*7.99*	*8.21*		*157*	*161*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.25*	*0.35*	*0.49*	*3*	*4*	*5*
LSD (p < 0.05)	*NS*	*1.01*	*NS*	*NS*	*11*	*NS*

^{32}P based P-use efficiency parameters of kharif rice

The percent P derived from fertilizer by *kharif* rice dry matter at maximum tillering stage was significantly influenced by different rates of P. Highest Pdff was observed with 100% RDP, while lowest was observed with 25% RDP application. The interaction effect of years and treatments on Pdff by rice dry matter was significant. Phosphorus application at different levels significantly affected the P utilization by rice at maximum tillering stage. It increased significantly from 22.36% with 100% RDP to 38.10% with 25% RDP. The interaction of years and treatments on P utilization by rice was significant. The decrease in fertilizer P with increasing fertilizer dose may be due to high soil P in the experimental field. The mean fertilizer P uptake by rice dry matter was highest at 5.72 kg ha^{-1} when fertilizer was applied @ 100% RDP and was higher than any reduced level. The soil P uptake by *kharif* rice at maximum tillering stage was significantly affected by different rates of P. The lowest soil P uptake (15.18 kg ha^{-1}) was attained with application of 25% RDP. Phosphorus application @ 50 to 100% RDP gave at par soil P uptake by rice at maximum tillering stage.

Nutrient content and uptake by rice grain during rabi

The effects of reduced P levels on P content in *rabi* rice grain is given in table 3. Application of 100% RDP gave maximum mean P content (0.35%) in rice grain, while 50% RDP gave minimum mean P content of 0.34%. The *kharif* residual effect on *rabi* rice grain P content was highest of 0.35% where crop received 100% RDP during *kharif.* It was significantly superior to other treatments. However, P content in *rabi* rice grain was significantly lower in 0.33% when soil received 25% RDP in earlier *kharif* compared to other treatments.

The P uptake by *rabi* rice grain decreased significantly from 20.38 to 17.85 kg ha^{-1} with P application from 50 to 100% RDP (Table 3). The P uptake by *rabi* rice grain was maximum when 100% RDP was applied in *kharif* and was on par with 75% RDP applied in *kharif*. The interaction of *rabi* P treatments and residual *kharif* P rates on P uptake by *rabi* rice grain was significant. The combination applied 75 and 100% RDP with residual *kharif* P rates of 100 and 75% RDP gave highest P uptake in grain of rabi rice.

Effect of P on content and uptake of zinc in rabi rice grain

The effect of *rabi* P rates and different P rates in kharif on zinc content of *rabi* rice grain are given in table 3. Phosphorus application during *rabi* @ 50 to 100% RDP significantly increased the zinc content of rice grain in the range of 19.76 to 24.71 mg kg^{-1}. Different rates of P applied in *kharif* did not affect zinc content in *rabi* rice grain. However, there was a gradual decrease in zinc content of pooled *rabi* rice grain as P rates in *kharif* decreased. The interaction of *rabi* P rates and residual *kharif* rates on zinc content of *rabi* rice grain was significant. In general, *rabi* P rates of 75 and 100% RDP in combination with all residual *kharif* P rates gave significantly higher zinc content in *rabi* rice grain compared to 50% RDP of *rabi* + different levels of residual *kharif* P rates. The zinc uptake by *rabi* rice grain was significantly affected due to different rates of P received in *kharif*. Highest zinc uptake of 136 g ha^{-1} was observed in *rabi* rice grain when crop received 100% RDP in *kharif* and was at par with 75% RDP of *kharif*. The interaction effect of *rabi* treatments in conjunction with residual *kharif* P treatments was significant on zinc uptake by *rabi* rice grain.

Table 3. Effect of fertilizer P on content and uptake of P and zinc in *rabi* rice grain under rice-rice system

Treatments	P applied in *kharif*					P applied in *kharif*				
	100% RDP	75% RDP	50% RDP	25% RDP	Mean	100% RDP	75% RDP	50% RDP	25% RDP	Mean
Rabi	P Content (%)					Zinc content (mg kg^{-1})				
100% RDP	0.37	0.36	0.35	0.34	0.35	25.40	24.95	25.64	22.87	24.71
75% RDP	0.35	0.35	0.34	0.33	0.34	23.53	22.97	21.8	22.47	22.69
50% RDP	0.34	0.34	0.33	0.32	0.34	20.65	19.62	18.42	20.37	19.76
Mean	*0.36*	*0.35*	*0.34*	*0.33*		*23.19*	*22.51*	*21.95*	*21.90*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.014*	*0.013*	*0.026*			*0.77*	*0.67*	*1.35*		
LSD (p < 0.05)	*NS*	*NS*	*NS*			*NS*	*1.97*	*3.94*		
	P uptake (kg ha^{-1})					Zinc uptake (g ha^{-1})				
100% RDP	21.83	21.31	20.08	18.37	20.38	150	147	147	125	142
75% RDP	20.90	20.71	18.70	17.01	19.33	140	137	122	117	129
50% RDP	19.68	18.98	17.42	15.32	17.85	119	110	96	96	107
Mean	*20.80*	*20.33*	*18.71*	*16.90*		*136*	*131*	*125*	*113*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.47*	*0.43*	*0.88*			*3.94*	*3.51*	*7.02*		
LSD (p < 0.05)	*1.43*	*1.23*	*2.46*			*11.51*	*9.90*	*19.81*		

Effect of P on nutrient content and uptake of P in rabi rice straw

There was no significant effect of applied P doses on P content of rice straw during *rabi* (Table 4) but significantly affected P uptake by its straw in the range of 7.13 to 7.97 kg ha^{-1}. Phosphorus @ 75 and 100% RDP and 75 and 50% RDP gave at par P uptake by rice straw as given in table 5. The P uptake by rice straw during *rabi* increased with each increment of P applied earlier. However, P uptake by rice straw in *rabi* was on par in the plots during *rabi* when crop received 75 and 100% RDP in *kharif*. The interaction effect of *rabi* P doses and residual *kharif* treatments on P uptake by *rabi* rice straw was significant.

Table 4. Effect of fertilizer P on content and uptake of P and zinc in *rabi* rice straw under rice-rice system

Treatments	P applied in *kharif*					P applied in *kharif*				
	100% RDP	75% RDP	50% RDP	25% RDP	Mean	100% RDP	75% RDP	50% RDP	25% RDP	Mean
Rabi	P Content (%)					Zinc content (mg kg^{-1})				
100% RDP	0.133	0.134	0.130	0.125	0.130	29.59	29.36	28.64	28.82	29.10
75% RDP	0.143	0.127	0.125	0.119	0.128	29.10	28.48	27.50	26.75	27.96
50% RDP	0.138	0.125	0.123	0.116	0.126	27.84	27.43	26.91	24.69	26.72
Mean	*0.138*	*0.128*	*0.126*	*0.12*	*0.128*	*28.84*	*28.42*	*27.69*	*26.75*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.002*	*0.002*	*NS*			*0.71*	*0.61*	*1.22*		
LSD (p < 0.05)	*0.001*	*0.001*	*NS*			*NS*	*1.78*	*3.56*		
	P uptake (kg ha^{-1})					Zinc uptake (g ha^{-1})				
100% RDP	8.64	8.53	7.78	6.94	7.97	197	182	173	168	180
75% RDP	8.94	8.11	7.14	6.48	7.66	183	176	156	146	165
50% RDP	9.14	6.88	6.68	5.88	7.13	184	151	146	129	153
Mean	*8.90*	*7.84*	*7.20*	*6.43*		*188*	*170*	*158*	*147*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.28*	*0.26*	*0.52*			*4.99*	*4.12*	*8.3*		
LSD (p < 0.05)	*0.80*	*0.69*	*1.38*			*14.5*	*12.9*	*25.8*		

Table 5. Effect of fertilizer P on content and uptake of P and zinc in *kharif* rice grain under rice–sunflower system

Treatments	2009	2010	Mean	2009	2010	Mean
P content (%)				Zinc content (mg kg^{-1})		
100% RDP	0.35	0.35	0.35	24.69	25.16	24.93
75% RDP	0.34	0.34	0.34	24.65	24.86	24.76
50% RDP	0.33	0.33	0.33	22.58	22.91	22.75
25% RDP	0.33	0.33	0.33	20.42	20.55	20.49
Mean	*0.34*	*0.34*		*23.09*	*23.37*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.01*	*0.011*	*0.022*	*0.37*	*0.53*	*0.75*
LSD (p < 0.05)	*NS*	*NS*	*NS*	*NS*	*1.55*	*NS*
P uptake (kg ha^{-1})				Zinc uptake (g ha^{-1})		
100% RDP	19.80	19.93	19.86	140	144	142
75% RDP	19.83	19.87	19.85	143	144	144
50% RDP	17.85	18.03	17.94	122	124	123
25% RDP	17.24	17.34	17.29	107	116	111
Mean	*18.68*	*18.79*		*128*	*132*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.40*	*0.56*	*0.78*	*2.48*	*3.50*	*4.95*
LSD (p < 0.05)	*NS*	*1.62*	*NS*	*NS*	*10.02*	*NS*

Effect of P levels on content and uptake of zinc in rabi rice straw

The zinc content in *rabi* rice straw remained at par due to 100 and 75% RDP in *rabi*. Different rates of P applied in preceding *kharif* did not affect zinc content of *rabi* rice straw. However, there was a gradual decrease in zinc content of *rabi* rice straw from 28.84 to 26.75 mg kg^{-1} (P applied in earlier *kharif*) decreased from 100 to 25% RDP. In general, high rates of P applied in *rabi* as well as *kharif* gave higher zinc content in *rabi* rice straw. The zinc uptake by *rabi* rice straw increased significantly with increased rates from 50 to 75 and 75 to 100% RDP (Table 6). It was significantly influenced by rates of P applied in *kharif*. Highest zinc uptake of 188 g ha^{-1} was recorded in *rabi* rice straw when 100% RDP was applied in *kharif* rice and was on par with 75% RDP applied in preceding *kharif*. The uptake was on par in the plots that received 25 and 50% RDP in *kharif*.

Table 6. Effect of fertilizer P on content and uptake of P and zinc in *kharif* rice straw under rice–sunflower system

Treatments	2009	2010	Mean	2009	2010	Mean
P content (%)				Zinc content (mg kg^{-1})		
100% RDP	0.15	0.15	0.15	29.45	29.39	29.42
75% RDP	0.14	0.14	0.14	28.72	28.92	28.82
50% RDP	0.14	0.14	0.14	27.82	27.58	27.70
25% RDP	0.13	0.13	0.13	26.01	26.29	26.15
Mean	*0.14*	*0.12*		*28.00*	*28.04*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.010*	*0.015*	*0.020*	*0.42*	*0.60*	*0.84*
LSD (p < 0.05)	*NS*	*NS*	*NS*	*NS*	*1.73*	*NS*
P uptake (kg ha^{-1})				Zinc uptake (g ha^{-1})		
100% RDP	8.75	8.80	8.78	172	173	172
75% RDP	7.96	8.49	7.92	163	162	163
50% RDP	7.84	7.64	7.74	156	153	155
25% RDP	6.91	6.89	6.90	137	139	138
Mean	*7.86*	*7.80*		*157*	*158*	
	Y	*T*	*Y x T*	*Y*	*T*	*Y x T*
SEm (±)	*0.26*	*0.37*	*0.52*	*3.37*	*4.76*	*6.72*
LSD (p < 0.05)	*NS*	*1.07*	*NS*	*NS*	*13.9*	*NS*

^{32}P based P-use efficiency parameters of rabi rice

The effect of *kharif* residual P and *rabi* applied P levels on Pdff by rice dry matter at maximum tillering stage in *rabi* was significant. Increased rates of P applied in *rabi* significantly increased Pdff by rice dry matter. The difference in Pdff between any two levels of RDP was significant. However, the Pdff under these treatments remained in narrow range of 22.25 to 23.10%. Highest Pdff of 26.72% was recorded due to combination of 100% RDP of *rabi* P in the plot that received 100% RDP in *kharif*.

The P utilization by *rabi* rice at maximum tillering stage decreased with increased rate of *rabi* P. The decrease with increased rate of P was significant for each consecutive level. It ranged from 25.31 to 29.34% due to *kharif* dose of 25 to 100% RDP. The P utilization of *rabi* dry matter remained on par with *kharif* applied 100 and 75, 75 and 50 and 50 and 25% RDP. The interaction effect of P levels applied fresh and *kharif* residual levels on P utilization by *rabi* rice dry matter was significant. The combination of 50% RDP of *rabi* dose in conjunction with any level of P applied in *kharif* gave significantly higher P utilization by *rabi* rice dry matter compared to corresponding combination of 75 and 100% RDP with *kharif* applied P levels.

The fertilizer P uptake of *rabi* rice dry matter was significantly influenced due to various levels of RDP applied to previous *kharif* crop and ranged from 3.60 to 5.31 kg ha^{-1}. Interaction effect of freshly applied *rabi* P with *kharif* residual P levels on fertilizer P uptake by *rabi* rice dry matter was significant. Maximum fertilizer P uptake was attained at higher levels of P applied (100 and 75% RDP) both in *rabi* and preceding *kharif*.

The soil-P uptake by *rabi* rice dry matter was significantly higher (15.35 kg ha^{-1}) with 100% RDP in *rabi* and was significant compared to other levels of P. It remained at par due to 50 and 75% RDP in *rabi*. The *kharif* P levels significantly affected soil P uptake by rice dry matter in *rabi*. It decreased gradually from 15.45 to 13.69 kg ha^{-1} with decrease in rate of P in *kharif* from 100 to 25% RDP. The difference in soil P uptake between any consecutive P rates was non-significant but the difference between 100 and 25% RDP was significant.

Rice-sunflower system

Effect of P on nutrient content and uptake of P in kharif rice

The P content of rice grain during *kharif* was at par across treatments and years (Table 5). The P uptake by rice grain during *kharif* indicated that it was significantly affected by P applied to the crop at different rates. The P uptake of grain due to 75% RDP was 19.85 kg ha^{-1} and was at par with 100% RDP and significantly superior to 50% RDP (17.94 kg ha^{-1}).

Effect of P on content and uptake of zinc in rice grain

The zinc content of rice grain during *kharif* was significantly influenced by levels of P applied to the crop (Table 5) mgkg^{-1}. Application of 75 and 100% RDP recorded similar zinc content of 24.76 and 24.93mgkg^{-1} respectively. However lower doses of P applied beyond 75% RDP resulted in significantly lower zinc content in rice grain. Application of lower doses of P @ 25 and 50% RDP gave significantly lower zinc uptake by rice grain compared to 75 and 100% RDP.

Effect of P on nutrient content and uptake of P in rice straw

The P content in rice straw during *kharif* was not influenced by the levels of P application. It is also observed that there was no significant difference in P content of rice straw due to effect of years and treatment or years(Table 6). The P uptake by *kharif* straw as affected by different levels of P application indicated that it was highest due to 100% RDP dose. However, uptake was on par with that of 75% RDP.

Effect of P on content and uptake of zinc in rice straw

The zinc content in *kharif* rice straw decreased significantly with reduced levels of P application (Table 6). The zinc content of rice straw was significantly higher due to 100% RDP over 25% RDP. The zinc content of *kharif* rice straw was not influenced by interaction of years and treatments. The zinc uptake by *kharif* rice straw indicated that it was minimum (138 kg ha$^{-1)}$ when P was applied @ 25% RDP. Highest zinc uptake by straw was obtained due to application of 100% RDP and it was on par with that of 75% RDP.

^{32}P based P-use efficiency parameters of kharif rice crop

The Pdff by *kharif* rice dry matter at maximum tillering stage was significantly affected by P applied to the crop. The Pdff in rice dry matter ranged from 16.23 to 26.17%. The effect of years of on Pdff by *kharif* rice was not significant. However, interaction of years and treatments on Pdff by rice dry matter was significant. The P utilization by rice dry matter at maximum tillering stage increased significantly from 22.36% (100% RDP) with each decrement of P to 38.04% by P applied @ 25% RDP.

The fertilizer P uptake by rice dry matter was lowest (3.04 kg ha^{-1}) due to 25% RDP and highest (5.55 kg ha^{-1}) due to 100% RDP. The fertilizer P uptake by rice dry matter at maximum tillering stage was not affected by years or interaction of years and treatments. The soil-P uptake by rice dry matter at maximum tillering stage during *kharif* indicated that it was highest when crop was supplied with 100% RDP (16.36 kg ha^{-1}) and was on par with 75 and 50% RDP. However, soil P uptake recorded due to 75 or 50% RDP was significantly higher than that of 25% RDP (13.80 kg ha^{-1}).

Effect of P on nutrient content and uptake of P in sunflower seed

Phosphorus content in *rabi* sunflower seed decreased from 0.39 to 0.37% with reduced P application to *rabi* sunflower from 100 to 50% RDP (Table 7). The P uptake decreased in *rabi* sunflower seed as P application to *rabi* crop decreased from 100 to 75% RDP but P uptake at 100% RDP was significantly higher over 50% RDP. However, P uptake by *rabi* sunflower that received 75 and 100% RDP in earlier *kharif* was significantly higher over 25 and 50% RDP applied in *kharif*. The cumulative effect of *kharif* and *rabi* applied P significantly affected P uptake by *rabi* sunflower seed. The combination of 100 and 75% RDP applied in *rabi* with 100 or 75% RDP in *kharif* were at par and higher compared to lower doses.

Table 7. Effect of fertilizer P on content and uptake of P and zinc in sunflower seed under rice–sunflower system

Treatments	P applied in *kharif*					P applied in *kharif*				
	100% RDP	75% RDP	50% RDP	25% RDP	Mean	100% RDP	75% RDP	50% RDP	25% RDP	Mean
Rabi	P content (%)					Zinc content (mg kg^{-1})				
100% RDP	0.41	0.39	0.39	0.36	0.39	31.22	30.57	29.17	28.69	29.91
75% RDP	0.40	0.40	0.39	0.35	0.39	29.87	28.59	28.41	27.51	28.60
50% RDP	0.39	0.38	0.37	0.34	0.37	28.45	27.56	27.12	26.43	27.39
Mean	*0.40*	*0.39*	*0.38*	*0.35*	*0.38*	*29.85*	*28.91*	*28.23*	*27.54*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.01*	*0.01*	*0.02*			*0.80*	*0.70*	*1.39*		
LSD (p < 0.05)	*NS*	*NS*	*NS*			*2.35*	*2.03*	*4.05*		
	P uptake (kg ha^{-1})					Zinc uptake (g ha^{-1})				
100% RDP	7.22	6.77	5.85	5.28	6.26	55.01	53.04	43.78	42.06	48.34
75% RDP	7.15	6.56	5.60	4.90	6.03	53.38	46.92	40.77	38.51	44.77
50% RDP	6.40	5.90	5.11	4.44	5.44	46.66	42.80	37.48	34.49	40.26
Mean	*6.92*	*6.41*	*5.52*	*4.87*		*51.62*	*47.49*	*40.64*	*38.29*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.24*	*0.21*	*0.42*			*1.27*	*1.08*	*2.15*		
LSD (p < 0.05)	*0.69*	*0.61*	*1.23*			*3.70*	*3.19*	*6.38*		

Effect of P on content and uptake of zinc in sunflower seed

The zinc content decreased significantly from 29.91 mg kg^{-1} due to 100% RDP applied in *rabi* to 27.39 mg kg^{-1} by 50% (Table 7). The effect of P applied in *kharif* significantly affected the zinc content of *rabi* sunflower seed. It decreased gradually with decreased P made in *kharif*. The difference between zinc content of *rabi* sunflower seed was highly significant when compared between residual effects of 100 and 25% RDP in *kharif*.

The zinc uptake by *rabi* sunflower seed was significantly influenced by application of P in *rabi* (Table 7). The zinc uptake of *rabi* sunflower seed in high P soil significantly decreased as P application made in *kharif* rice decreased at a regular interval. The interaction of direct *rabi* and *kharif* residual P indicated that 100% RDP of *rabi* in conjunction with 100 or 75% RDP in kharif resulted in similar zinc uptake in rabi sunflower seed.

Effect of P on nutrient content and uptake of P in sunflower stalk

There was non-significant decrease in P content in rabi sunflower stalk (Table 8) due to phosphorus applied in kharif crop (25 to 100% RDP).. The P uptake by rabi sunflower stalk significantly decreased as P application to rabi crop decreased from 100 to 50% RDP. These differences in reduction of P uptake were significant between any two successive levels of P. Phosphorus uptake by rabi sunflower stalk was significantly lower with each decrement rate of P applied to kharif rice. The P uptake decreased from 2.73 (100% RDP) to 1.54 kg ha^{-1} (25% RDP) applied in kharif. The interaction of rates of P applied in rabi and earlier kharif was significant on P uptake by rabi sunflower stalk.

Table 8. Effect of fertilizer P on content and uptake of P and zinc in sunflower stalk under rice–sunflower system

Treatments	P applied in *kharif*					P applied in *kharif*				
	100% RDP	75% RDP	50% RDP	25% RDP	Mean	100% RDP	75% RDP	50% RDP	25% RDP	Mean
Rabi	P content (%)					Zinc content (mg kg^{-1})				
100% RDP	0.12	0.10	0.09	0.08	0.10	19.65	18.74	17.60	16.94	18.23
75% RDP	0.10	0.09	0.08	0.07	0.09	18.31	17.98	17.17	16.27	17.43
50% RDP	0.09	0.08	0.07	0.07	0.08	17.69	17.27	16.58	15.58	16.78
Mean	*0.10*	*0.09*	*0.08*	*0.07*		*18.55*	*18.00*	*17.12*	*16.26*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.019*	*0.017*	*0.035*			*0.47*	*0.41*	*0.82*		
LSD (p < 0.05)	*NS*	*NS*	*NS*			*1.37*	*1.19*	*2.39*		
	P uptake (kg ha^{-1})					Zinc uptake (g ha^{-1})				
100% RDP	3.30	2.57	2.03	1.71	2.37	54.01	48.14	39.76	36.20	44.28
75% RDP	2.76	2.33	1.77	1.44	2.05	50.52	46.64	37.93	33.58	41.95
50% RDP	2.17	1.93	1.44	1.48	1.74	42.67	41.62	34.09	32.86	37.70
Mean	*2.73*	*2.27*	*1.74*	*1.54*		*48.97*	*45.43*	*37.22*	*34.21*	
	KT	*RT*	*KT x RT*			*KT*	*RT*	*KT x RT*		
SEm (±)	*0.11*	*0.09*	*0.18*			*1.49*	*1.32*	*2.63*		
LSD (p < 0.05)	*0.31*	*0.27*	*0.54*			*4.35*	*3.85*	*7.67*		

Effect of P levels on content and uptake of zinc in sunflower stalk

The zinc content of *rabi* sunflower stalk decreased gradually and significantly as level of P applied in *rabi* decreased (Table 8). It was significantly lower at 50 and 25% RDP applied in *kharif* rice than 100% RDP. The interaction of rates of P applied in *rabi* and in preceding *kharif* rice significantly affected zinc content of *rabi* sunflower stalks. The cumulative effect of 100% RDP of *kharif* along with 100% RDP of *rabi* was at par with 100% RDP of *rabi* + 75% RDP of *kharif* (18.74 mg kg^{-1}).

The zinc uptake by *rabi* sunflower stalk was at par due to *rabi* P application at 100 and 75% RDP (Table 8). The zinc uptake was significantly lower (37.7 g ha^{-1}) in stalks when 50% RDP was applied. Decreasing rate of P application to *kharif* rice decreased zinc uptake by subsequent *rabi* sunflower stalks. The cumulative effect of P applied during both seasons significantly influenced the zinc uptake by *rabi* sunflower stalk.

^{32}P based P-use efficiency parameters of rabi sunflower

Pdff by sunflower dry matter at bud initiation stage

The Pdff decreased significantly when *rabi* P application was reduced from 100 to 75% RDP and it remained at par with 50% RDP crop. The residual effect of *kharif* P significantly affected the Pdff by *rabi* sunflower dry matter. It decreased significantly when rate of P applied in *kharif* decreased from 100 to 75% RDP. The Pdff by sunflower dry matter was highest (29.34%) due to cumulative effect of RDP @ 100% during *rabi* and earlier *kharif* rice.

Per cent P utilization by sunflower dry matter at bud initiation stage

The P utilization increased significantly from 6.67 to 9.46% with decrease in rate of *rabi* P application. The difference in P utilization by *rabi* sunflower dry matter between any two levels of P applied in *rabi* was significant. The P applied in *kharif* rice significantly reduced the P utilization by sunflower dry matter with each decrement in rates of *kharif* P application. The residual effect resulted in decreased P utilization by sunflower from 10.47 to 5.75%. The interaction of *kharif* and *rabi* P levels on P utilization by sunflower dry matter was significant.

Fertilizer P uptake by sunflower dry matter at bud initiation stage

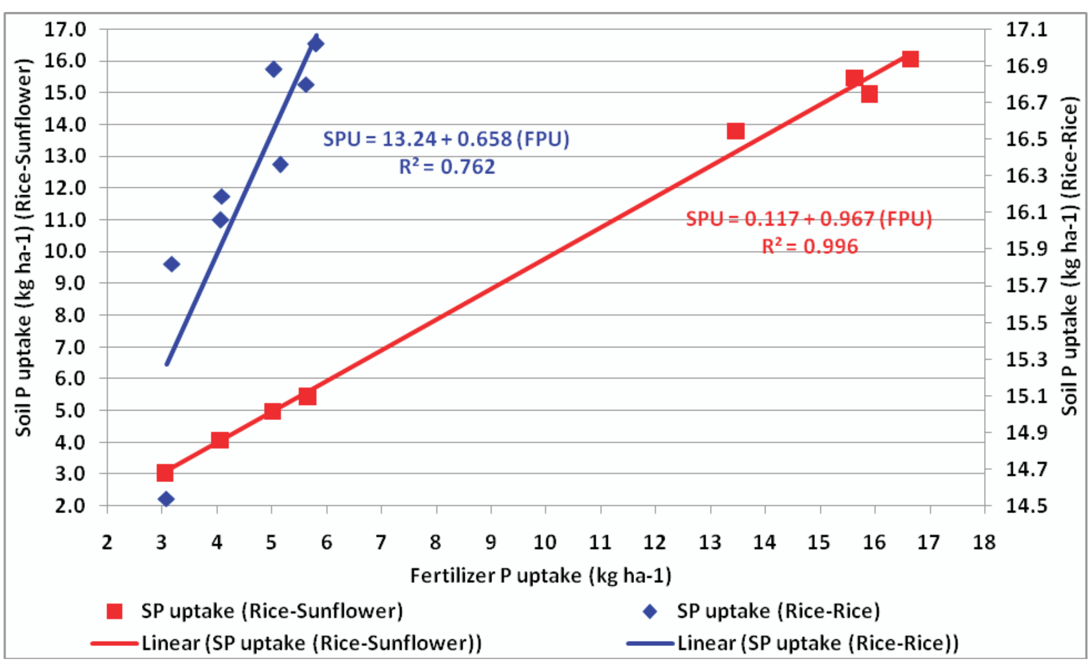
The fertilizer P uptake by *rabi* sunflower dry matter decreased significantly with each decrement in P application. The fertilizer P uptake decreased from 2.02 to 1.04 kg ha^{-1} significantly with each level of reduced P application in rice. The interaction of rates of P applied in *rabi* and preceding *kharif* rice indicated that highest P uptake of 2.35 kg ha^{-1} could be attained with 100% RDP in both seasons.

Soil P uptake by sunflower dry matter at bud initiation stage

The soil P uptake by sunflower dry matter recorded at 50% RDP in *rabi* was significantly lower (4.47 kg ha^{-1}) over 75 or 100% RDP. It decreased significantly due to 50 or 25% RDP in *kharif* than 100% RDP of *kharif*. The interaction effect of 100% RDP applied in both seasons, 100% RDP of *kharif* + 75% RDP of *rabi* and 100% RDP of *rabi* + 75% RDP of *kharif* were significantly higher compared to lower rate combinations of *kharif* and *rabi* seasons.

Relationship between fertilizer P and soil P uptake in different systems

The relationship between fertilizer and soil P uptake in *kharif* and *rabi* rice under rice-rice and rice-sunflower systems are depicted in Fig 1. In *kharif*, there was a significantly higher predictability of 0.99 under rice-sunflower compared to 0.76 under rice-rice system. The rate of change in soil P uptake for an unit change in fertilizer P uptake was also higher in rice-sunflower system (0.96 kg ha^{-1}) compared to rice-rice system (0.65 kg ha^{-1}). In *rabi* season, there was a significantly higher predictability of 0.90 under rice-sunflower compared to 0.67 under rice-rice system. The rate of change in soil P uptake for an unit change in fertilizer P uptake was also higher in rice-sunflower system (1.27 kg ha^{-1}) compared to rice-rice system (1.09 kg ha^{-1}).



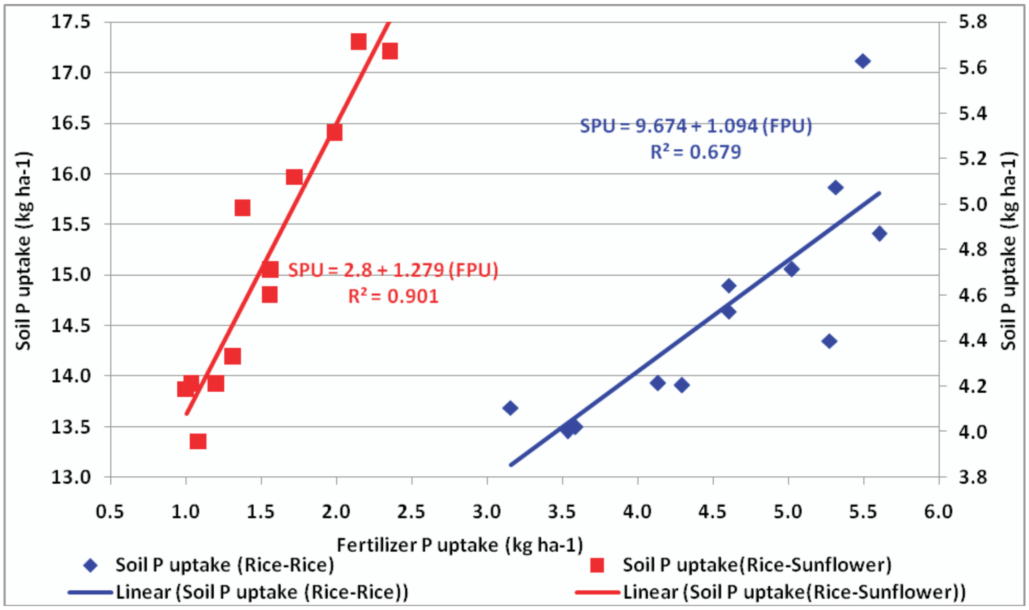
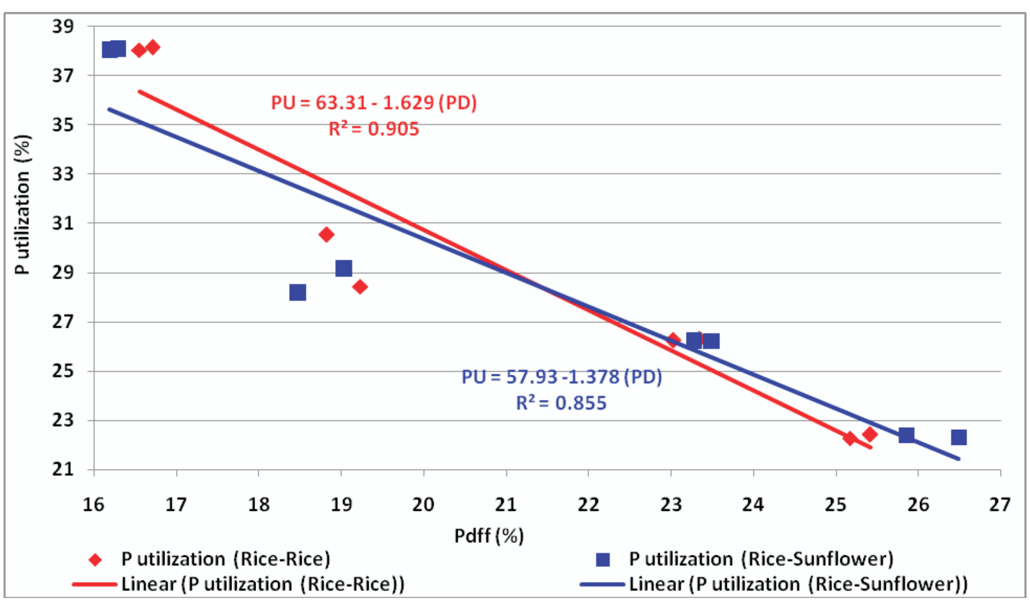


Fig. 1. Relationship between fertilizer and soil P uptake in *kharif* and *rabi* seasons under rice-rice and rice-sunflower systems

Relationship between P utilization and Pdff in different systems

The relationship between P utilization and Pdff under rice-rice and rice-sunflower systems are depicted in Fig 2. There was a negative relationship between Pdff and P utilization in *kharif* and *rabi* under rice-rice and rice-sunflower systems. In *kharif*, there was a significantly higher predictability of 0.905 under rice-rice compared to 0.855 under rice-sunflower system. The rate of change in P utilization for an unit change in Pdff was higher in rice-rice (1.629%) compared to rice-sunflower system (1.378 kg ha^{-1}). In *rabi*, there was a significantly higher predictability of 0.845 under rice-rice compared to 0.219 under rice-sunflower system. The rate of change in P utilization for an unit change in Pdff was also higher in rice-rice (-2.552%) compared to rice-sunflower system (0.331%).



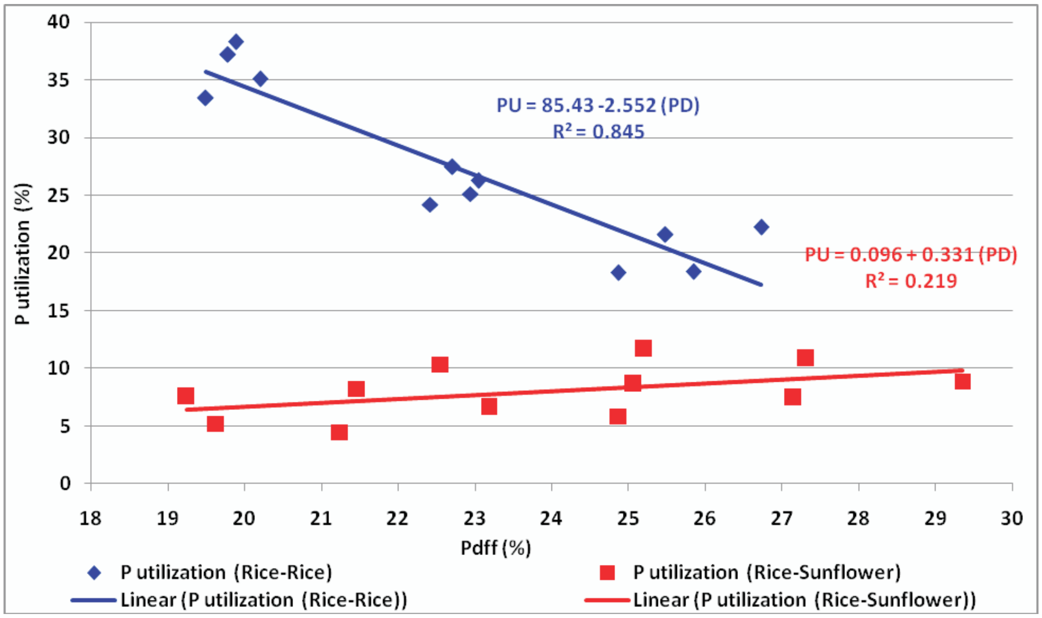


Fig. 2. Relationship between Pdff and P utilization in *kharif* and *rabi* seasons under rice-rice and rice-sunflower systems

Effect of P application on rice under rice-rice and rice-sunflower systems

Application of P during *kharif* to rice either in rice-rice or rice-sunflower systems indicated that rice grain yield remained similar due to 100 and 75% RDP. In rice-rice system, the grain yield was at par in the range of 5668 to 5775 kg ha^{-1} with application of P @ 75 to 100% RDP. Similarly, rice grain yield remained at par due to treatments in pooled *kharif* rice of rice-sunflower system. Higher soil P of 126 kg P_2O_5 ha^{-1} was beneficial to attain at par rice yield when recommended dose was reduced by 25%. Reduction in RDP to 50% gave lower yields compared to 75 or 100% RDP. Hence there is a possibility of saving 25% dose in P recommendation to *kharif* rice. Surendra Babu *et al*. (2006) reported that in high P soils having available P_2O_5 range of 62 to 94, it is possible to reduce P dose to rice by 25%. The P content in *kharif* rice grain and straw of both systems was not affected due to different P levels. The P uptake by rice grain ranged from 17.4 to 19.97 kg ha^{-1} due to different rates of P in rice under rice-rice system and from 17.29 to 19.86 kg ha^{-1} in *kharif* rice under rice-sunflower system. The increased P uptake by rice grain at 100% RDP was because of higher yield realization.

In spite of initial soil DTPA Zn of 3.1 mg kg^{-1}, the Zn content of rice grain decreased under both cropping systems with a reduction in the RDP levels. Such a decrement in Zn content of rice grain was noticed for rice under rice-sunflower system. Bogdavonic *et al* (1999) reported that high P level in soil would reduce availability of zinc to crops. However, increased rates of P from 25 to 100% slightly increased Zn content of grain and straw of *kharif* rice. This was due to the fact that soil had high P and sufficient available Zn and rate of applied P was below the recommended dose. Similar trend was observed in Zn content in *kharif* rice straw.

The Pdff of rice dry matter in *kharif* got reduced from 25.29 to 16.62% in rice-rice system and from 26.22 to 16.20% in rice-sunflower system as rate of P application was reduced from 100 to 25% RDP. Increased Pdff and fertilizer P uptake by crops with increased rate of P application was observed as reported for low to medium soils for other crops (Giri and Venkata Reddy 2005).

Thus, utilization of applied P by *kharif* rice increased significantly with reduced P application. The P utilization by *kharif* rice dry matter was 70% higher due to 25% RDP compared to 100% RDP. The soil P uptake reduced with decreased rate of P application and ranged from 13.8-16.91 kg ha^{-1} across different treatments of rice dry matter under both systems.

Effect of rabi applied P and kharif residual P on rabi rice of rice-rice system

The *rabi* rice grain yield was significantly affected fertilizer application in rabi. However, P @ 100 and 75% RDP of *rabi* gave at par yield of 5654 and 5760 kg ha^{-1}. Similar trend was observed in straw yield. Phosphors can be reduced by 25% in *rabi* rice of rice-rice system. The grain and straw yields decreased from 5876 to 5130 and 6319 to 5361 kg ha^{-1} respectively as *kharif* P dose decreased from 100 to 25% RDP. The yields obtained in plots that received either 100 or 75% RDP in *kharif* resulted in at par yield in *rabi*. In a medium P soil, Rao *et al* (1989) tried different P levels in rice based system and reported that rice yield increased due to residual effect of P @ 80 and 120 kg ha^{-1} in earlier crop. In present study, yields were maintained even after reducing 25% of RDP but decreased when reduction was beyond 25%.

The cumulative effect also indicated that *rabi* grain and straw yield can be same even when 100% RDP was applied in *rabi* to plots that received 50% RDP in *kharif*. However, across both seasons, there was a possibility of saving P by 25% in *kharif* + 25% in *rabi* although 100% P in *rabi* applied to plots that received 50% RDP in *kharif* was similar. The P uptake of *rabi* rice grain and straw decreased considerably due to reduced P application of either fresh *rabi* levels of P or residual levels of *kharif* applied P. Similar results were reported by Surendra Babu *et al.,* (2005) for maize raised on a high P soil.

The Zn content of *rabi* rice grain and straw decreased with decrease in P application in *rabi* or *kharif* to previous crop. It appeared that whenever recommended P was applied, Zn content of crop was at highest level. The lower levels of Zn content was above to normal content registered in crop produce. Gill *et al* (2004) observed that P induced reduction in shoot Zn concentration ranged between 22% in maize to 50% in sunflower. They revealed that differential P and Zn use efficiencies of maize and sunflower caused significant difference in P-Zn interactions.

The Pdff of *rabi* rice dry matter decreased as rate of P reduced in *rabi* and *kharif*. The reduction in Pdff due to *rabi* P application was significant and reflected similar results like direct effect of P on Pdff of rice dry matter in *kharif*. Residual effect of *kharif* applied P was not affecting Pdff in *rabi* and it is expected that P was tagged freshly to *rabi* P only. Similarly, Pdff continued to be higher due to combination of freshly applied 100% *rabi* RDP in conjunction with any P rate applied to preceding *kharif*. The fertilizer P uptake of *rabi* rice dry matter was higher when crop received combined dose of 75 or 100% RDP in both seasons. The P utilized by *rabi* crop remained higher with lower rates of P of either *rabi* or *kharif*. It is clear from Pdff, fertilizer P uptake and P utilization of *rabi* rice that *kharif* applied P helped in *rabi* to realize higher P utilization by crop than what could be achieved in terms of Pdff and fertilizer P uptake. The soil P uptake by *rabi* rice dry matter was lower than that of *kharif*.

Effect of rabi applied P, kharif residual P and cumulative influence on sunflower

Application of fresh P levels during *rabi* indicated that sunflower seed yield was at par irrespective of 100 or 75% RDP application indicating that there was a possibility of reducing P by 25% RDP of sunflower. However, reducing RDP beyond 25% resulted in similar yield like that of 75% RDP but not 100% RDP. The stalk yield of sunflower also resulted in a similar trend. The cumulative study indicated that 25% RDP each in *kharif* rice and *rabi* sunflower could be adopted to attain similar yields of seed and stalk.

The zinc content gradually decreased in sunflower seed and stalk from 29.91 to 27.39, 18.23 to 16.78 mg kg^{-1} where P was applied to *kharif* crop. Similar trend was reflected in Zn uptake of both seed and stalk of sunflower. This observation made for crop and reasons ascribed for such phenomenon were discussed in *rabi* rice of rice-rice system.

^{32}P isotope was employed in sunflower of rice-sunflower system. The applied *rabi* P decreased Pdff of sunflower dry matter at bud initiation stage from 25.8 to 22.1% as P levels were reduced. The residual effect of *kharif* treatments indicated that Pdff decreased from 27.3 to 20.3%

as P applied in rice decreased from 100 to 25% RDP. This was in contrast to what was observed in *rabi* rice of rice-rice system where Pdff remained similar across *kharif* residual P treatments. The reason for such difference between Pdff of rice and sunflower in *rabi* under rice based system needs to be investigated.

The fertilizer P uptake by sunflower dry matter at bud initiation stage ranged from 1.27 to 1.78 kg ha^{-1} as P application increased from 50 to 100% RDP. The fertilizer P uptake decreased with lower levels of P as in Pdff. Phosphorus application made in *kharif* also reduced (2.02 to 1.04 kg ha^{-1}) fertilizer P uptake in sunflower in proportion to decremental levels of *kharif* P. The combined effect of *kharif* and *rabi* P application gave high fertilizer P uptake by sunflower dry matter due to 100 or 75% RDP applied during *rabi* on plots that received 100% RDP in *kharif*. The P utilization of applied P by sunflower dry-matter decreased with increment of *rabi* P application as plots that received P in *kharif* got reduced from 100 to 25%. The soil P uptake by sunflower dry matter during *rabi* was lower with reduced P of *rabi* dose. The residual effect of *kharif* P also indicated reduced soil P uptake from 5.38 to 4.09 kg ha^{-1} as *kharif* P dose decreased from 100 to 25% RDP. Decreased soil P uptake at lower level of *kharif* or *rabi* treatments was due to lower yield realization as implied in total P removal by crop. The study indicated that 25% P fertilizer could be saved from current recommended dose in both crops. Phosphorus removal by rice and sunflower was at par for 100 and 75% RDP applied to both crops. Thus reducing P by 25% from current RDP of rice and sunflower in both cropping systems would be efficient for attaining maximum yield, uptake and fertilizer use efficiency under high P soils.

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