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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

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Abstract

Field experiment was conducted during dry seasons for 2 consecutive years at College of Agriculture, Rajendranagar, Hyderabad on no-till maize after lowland *kharif* rice on sandy clay loam soil. The experiment was laid out in randomized block design with factorial concept and replicated thrice. Treatments executed are three Phosphorus levels (30, 45 and 60 kg P_2O_5 ha^{-1}) and three Phosphorus application times (at 10 days before harvest of rice, at the time of sowing of maize and at the time of first irrigation to maize). The results revealed that application of 60 kg P_2O_5 ha^{-1} recorded superior grain and stover yield, gross returns, net returns, benefit cost ratio and nutrient uptake (Nitrogen, Phosphorus and Potassium) at crop harvest over that of 45 and 30 kg P_2O_5 ha^{-1}. But, application of 60 kg P_2O_5 ha^{-1} left behind the soil with lower amount of available Nitrogen and Potassium and higher Phosphorus status after harvest of the crop. Application of phosphorus at 10 days before harvest of rice and at the time of sowing of maize being on par resulted in better grain and stover yield of maize, gross returns, net returns, benefit cost ratio and nutrient uptake (Nitrogen, Phosphorus and Potassium) at crop harvest over its delayed application (at the time of first irrigation to maize). The application of Phosphorus at 10 days before harvest of rice or at the time of sowing of maize depleted greater amount of available Phosphorus from the soil than its application along with first irrigation.

Keywords: Maize, no-till, nutrients, phosphorus, returns, time, uptake, yield

1. Introduction

Maize is the world's most important cereal crop next to rice and wheat (Singh et al., 2012) grown in an area of 201.9 mha with productivity around 5.75 t ha^{-1} and production of 1162.3 mt (Anonymous, 2020a). It has wider adaptability under varied agro-climatic conditions (Arya et al., 2015) and successful cultivation in diverse seasons and ecologies for various purposes (Ramachandiran et al., 2016, Yadav et al., 2016, Singh et al., 2018, Shyam et al., 2021). In India it is grown in an area of 9.57 mha producing around 28.77 mt with an average yield of 3.01 t ha^{-1} (Anonymous, 2020b).

Rice-rice is one of the predominant cropping systems followed in India. In Telangana double cropping of rice is difficult to practice due to scarcity of irrigation water especially during *rabi* season. To meet the ever-increasing demand for maize, it can be introduced after *kharif* rice; because of its lower water requirement and suitability. In command areas *rabi* maize sowings are being delayed when farmers resort for conventional land preparation resulting in lower yields there by 'late planting' has become a major constraint. This constraint can be avoided by sowing maize under no-till condition after rice harvest.

No-tillage is the practice of sowing crops directly in the residues of the previous crop without cultivation, while stubbles are retained and weeds are controlled with herbicide (Labios et al., 2002). Zero tillage would reduce the soil erosion and loss of soil organic matter (Lal, 2004, Chalise et al., 2020, Kumar et al., 2018) and increase yield (Upasani et al., 2017). Besides the soil and water conservation (Sreelatha et al., 2015, Das et al., 2018, Malathi et al., 2018, Jat et al., 2019), it also reduces fuel consumption (Lal et al., 2019, Nandan et al., 2021), labour requirement and turnaround time.

Among the various inputs, Phosphorus is one of the most limiting nutrients in agricultural cropping systems (Jat et al., 2012, Roberts and Johnston, 2015, Guignard et al., 2017, Khan et al., 2018). The application of essential plant nutrients in optimum quantity (Amanullah and Khan, 2015) through correct method (Alam et al., 2018) and time of application is the key for the increased and sustained crop production (Cisse and Amar, 2000). More efficient utilization of Phosphorus is achieved by applying Phosphorus fertilizer shortly before planting the crop (Griffith, 1983). The positive effect of higher rates of phosphorus application on growth and development of maize was observed by Arya and Singh (2000), Howard et al. (2002), Chaudhary et al. (2012), Wu et al. (2015) and Keteku et al. (2017). Amanullah et al. (2010a) and Durani et al. (2019) reported that the increased dry matter was due to improved crop growth rate and LAI at higher Phosphorus levels.

Contrarily, reduced growth of wheat at its early stages in rice-wheat system was noticed by Muirhead (1974) and Dear et al. (1979) and they stated that the lower growth of wheat following rice was due to binding of 'Phosphorus' by iron compounds. In addition, lower growth of wheat or maize after rice might be attributed to increased Phosphorus sorption and its reduced availability and uptake by maize or wheat (Saleque et al., 2006). Studies on the proper combination of levels and time of Phosphorus application to no-till maize after lowland rice have not been carried out which is indispensable for sustainable and higher crop production.

Keeping these things in view, the investigation of "Phosphorus levels and its time of application to no-till maize after *kharif* lowland rice" was executed with an objective to examine the precise quantity and time of application of phosphatic fertilizer to maize.

2. Materials and Methods

2.1. Study site

The current study on "Phosphorus levels and its time of application to no-till maize after *kharif* lowland rice" was conducted in two successive years during *rabi* season (November to March) of 2007–08 and 2008–09 at the College of Agriculture, Rajendranagar, Hyderabad. The research site is geographically located at an altitude of 542.6 m above mean sea level on $17^0 19'$ North latitude and $78^0 27'$ East longitudes.

The texture of the soil of the experimental site (Sandy clay loam) was determined by Bouyoucos Hydrometer method (Piper, 1966), Organic carbon content (0.65%) by Walkley and Black method (Walkley and Black, 1934), the pH of the soil (8.37) was determined using glass electrode digital pH meter (Jackson, 1979). The electrical conductivity of the soil (0.40 d Sm^{-1}) was determined by conductivity meter (Jackson, 1979). The Soil was analyzed for available nitrogen (192.50 kg N ha^{-1}) by alkaline permanganate method (Subbaiah and Asija, 1956), available Phosphorus (17.34 kg P ha^{-1}) by Ascorbic acid method (Olsen et al., 1954) and available Potassium (187.0 kg K ha^{-1}) by Flame photometer method (Jackson, 1973).

2.2. Method of data collection

The experiment was laid out in randomized block design (factorial concept) with three replications at three Phosphorus levels viz., 30, 45 and 60 kg P_2O_5 ha^{-1} and three phosphorus application times viz., At 10 days before harvest of rice (Broadcast method in standing paddy crop), at the time of sowing of maize (Band placement) and at the time of first irrigation to maize (Band placement). The Maize hybrid (Super 900M) seeds were sown by dibbling method under no-till situation by adopting a spacing of 60 cm between rows and 20 cm between plants within a row during *rabi* season in the same plots without disturbing the layout, where *kharif* rice was grown in the previous season. The desired plant density was maintained in the different experimental plots by thinning one week after emergence of seedlings. The entire scheduled quantity of P_2O_5 was applied as per treatments through granular single super phosphate source. The recommended dose of Nitrogen @ 120 kg ha^{-1} was applied through Urea in three equal split doses at basal, knee high and tasselling stage of the maize crop. The entire recommended dose of K_2O (40 kg ha^{-1}) was applied as basal through Muriate of Potash. Recommended rate of non-selective herbicide (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 (1 kg a.i. ha^{-1} in 500 l of water) to the entire field. Irrigation and all other agronomic practices were followed uniformly for all the experimental plots.

The yield from the net plot (grain and stover) was weighed separately and converted to kg ha^{-1}. 5 plants collected for destructive sampling at harvest were shade dried followed by oven drying at 60°C to attain a constant weight. The grain and stover samples were finely ground and used for nutrient analysis (Nitrogen, Phosphorus and Potassium content) by adopting standard procedures. After the harvest of crop, treatment wise soil samples collected from 0–30 cm depth were analysed for available nutrient status (Nitrogen, Phosphorus and Potassium) following standard procedures (Piper, 1966).

The data collected for the above-mentioned characters were subjected to the following statistical analysis with the help of standard statistical procedures as given below.

2.3. Analysis of variance

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 (1985). 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

3.1. Grain and stover yield

Grain and stover yield of maize were influenced by both levels and time of application of phosphorus to a great extent (Table 1).

Table 1: Grain and Stover yield of maize as influenced by levels and time of Phosphorus application

Treatment	Grain yield (kg ha^{-1})		Stover yield (kg ha^{-1})	
	First Year	Second Year	First Year	Second Year
Factor 1: Phosphorus levels (P)				
P_1: 30 kg P_2O_5 ha^{-1}	4181	4208	5858	5749
P_2: 45 kg P_2O_5 ha^{-1}	4786	4706	6677	6408
P_3: 60 kg P_2O_5 ha^{-1}	5283	5034	7316	6827
SEm±	81	53	124	76
CD (p=0.05)	244	157	369	227
Factor 2: Phosphorus application time (T)				
T_1: At 10 days before harvest of rice	5020	4810	6882	6496
T_2: At the time of sowing of maize	4849	4741	6672	6437
T_3: At the time of first irrigation to maize	4383	4397	6297	6052
SEm±	81	53	124	76
CD (p=0.05)	244	157	369	227
Interaction (PXT)				
SEm±	141	91	214	131
CD (p=0.05)	N.S.	N.S.	N.S.	N.S.

Increased Phosphorus levels from 30–60 kg P_2O_5 ha^{-1} significantly enhanced the grain yield of maize. The grain yield with the application of 60 kg P_2O_5 ha^{-1} (5283 and 5034 kg ha^{-1}) was significantly higher over 45 kg P_2O_5 ha^{-1} (4786 and 4706 kg ha^{-1}) and 30 kg P_2O_5 ha^{-1} (4181 and 4208 kg ha^{-1}) during first and second years of the investigation, respectively. Likewise, higher stover yield was recorded with 60 kg P_2O_5 ha^{-1} (7316 and 6827 kg ha^{-1}) compared to 45 kg P_2O_5 ha^{-1} (6677 and 6408 kg ha^{-1}) and 30 kg P_2O_5 ha^{-1} (5858 and 5749 kg ha^{-1}) during two years of the investigation, respectively. The differences in stover yield between any two of the phosphorus levels were found significant.

Application of phosphorus at 10 days before harvest of rice (5020 and 4810 kg ha^{-1}) and at the time of sowing of maize (4849 and 4741 kg ha^{-1}) were found on par and recorded significantly superior grain yield over application of phosphorus at the time of first irrigation (4383 and 4397 kg ha^{-1}) during consecutive years of the research, respectively (Table 1). The delay in phosphorus supply upto first irrigation has significantly reduced stover yield (6297 and 6052 kg ha^{-1}) as compared to its application at the time of sowing of maize (6672 and 6437 kg ha^{-1}) or 10 days before harvest of rice in standing crop (6882 and 6496 kg ha^{-1}) respectively during 2 successive years.

The interaction owing to phosphorus levels and its time of application was not significant on grain and stover yields during both the years of study.

Similarly, Bharathi and Subba Rami Reddy (2010) reported that application of recommended dose of Phosphorus (60 kg P_2O_5 ha^{-1}) as band placement at the time of dibbling of maize seed or its application before harvesting of the paddy crop showed no significant variation in grain yield of rice fallow zero till maize.

Similar findings of higher grain and stover yield with the application of Phosphorus at 10 days before sowing or at the time of sowing of maize crop compared to its application at 15 days after sowing was reported by Amanullah et al. (2010b) who also opined that availability of Phosphorus is adequate when applied at 10 days before sowing or at the time of sowing; on the other hand, the decrease in grain and stover yield with late application of Phosphorus might be due to un availability of Phosphorus at early growth stage of the crop which is needed for root growth and development.

Higher values for these parameters were seen when phosphorus was given as basal application at the time of sowing of maize or in standing crop of rice 10 days before its harvest compared to application of phosphorus at the time of first irrigation to the crop (30DAS).

These results corroborate the findings of Dear et al. (1979), Narang et al. (1989), Howard et al. (2002), Gonigle and Miller (1996), Bharathi and Subba Rami Reddy (2010), Wu et al. (2015) and Keteku et al. (2017).

3.2. *Nutrient uptake*

Uptake of Nitrogen, Phosphorus and Potassium at harvest stage of the crop was significantly influenced by levels and time of phosphorus application (Table 2, 3 and 4).

Application of 60 kg P_2O_5 ha^{-1} increased the total uptake (kg ha^{-1}) of Nitrogen, Phosphorus and Potassium at harvest, respectively by 13.44, 2.89 and 8.56 over 45 kg P_2O_5 ha^{-1}, 34.24, 7.32 and 20.19 over 30 kg P_2O_5 ha^{-1} in first year, and by 12.10, 3.08 and 10.12 over 45 kg P_2O_5 ha^{-1} and 34.16, 6.76 and 19.93 over 30 kg P_2O_5 ha^{-1} in second year.

Similarly, application of phosphorus at 10 days before harvest of rice and at the time of sowing of maize crop showed significantly higher uptake of these nutrients at crop harvest over its application at the time of first irrigation to maize.

The increase in uptake of Nitrogen, Phosphorus and Potassium by maize at higher levels of Phosphorus was due to increased dry matter production as well as the nutrient concentration grain and stover (Sutaliya and Singh, 2005). These findings are in agreement with the findings of Narang et al. (1989), Arya and Singh (2000), Howard et al. (2002), Sreelatha et al. (2015) and Alam et al. (2018).

3.2.1. Nitrogen uptake

Data on nitrogen uptake presented (Table 2) revealed that

Table 2: Uptake of Nitrogen by maize as influenced by levels and time of Phosphorus application

Treatment	By Grain (kg ha^{-1})		By Stover (kg ha^{-1})		Total (Grain +Stover) (kg ha^{-1})	
	First year	Second year	First year	Second year	First year	Second year
Factor 1: Phosphorus levels (P)						
P_1: 30 kg P_2O_5 ha^{-1}	52.70	48.76	26.24	24.74	78.94	73.50
P_2: 45 kg P_2O_5 ha^{-1}	62.09	59.99	37.65	35.57	99.74	95.56
P_3: 60 kg P_2O_5 ha^{-1}	69.86	66.31	43.31	41.34	113.18	107.66
SEm±	1.05	0.66	0.69	0.40	1.58	0.84
CD (p=0.05)	3.15	1.96	2.07	1.20	4.74	2.51
Factor 2: Phosphorus application time (T)						
T_1: At 10 days before harvest of rice	65.49	61.57	38.53	35.53	104.02	97.10
T_2: At the time of sowing of maize	62.79	60.73	36.67	34.87	99.47	95.60
T_3: At the time of first irrigation to maize	56.38	52.76	32.01	31.24	88.38	84.01
SEm±	1.05	0.66	0.69	0.40	1.58	0.84
CD (p=0.05)	3.15	1.96	2.07	1.20	4.74	2.51
Interaction (PXT)						
SEm±	1.82	1.13	1.20	0.69	2.74	1.45
CD (p=0.05)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

nitrogen uptake by grain and stover separately as well as total uptake was significantly influenced by phosphorus levels and time of application of phosphorus.

Application of 60 kg P_2O_5 ha^{-1} recorded significantly higher nitrogen uptake (kg ha^{-1}) at harvest respectively by maize grain and stover separately, as well as total uptake (69.86, 43.31, 113.18 during first year and 66.31, 41.34, 107.66 during second year) over application of 45 kg P_2O_5 ha^{-1} (62.09, 37.65, 99.74 in first year and 59.99, 35.57, 95.56 in second year) and 30 kg P_2O_5 ha^{-1} (52.70, 26.24, 78.74 in first year and 48.76, 24.74, 73.50 in second year). The difference in Nitrogen uptake between latter two was also significant.

The uptake (kg ha^{-1}) of Nitrogen by grain, stover and total uptake, respectively by application of phosphorus at 10 days before harvest of rice (65.49, 38.53, 104.02 in first year and 61.57, 35.53, 97.10 in second year); and at the time of sowing of maize (62.79, 36.67, 99.47 in first year and 60.73, 34.87, 95.60 in second year) were significantly higher over its application at the time of first irrigation to maize (56.38, 32.01, 88.38 in first year and 52.76, 31.24, 84.01 in second year); however, the differences in uptake of nitrogen between former two were not significant during both the years of study.

Similarly, Application of 90 kg P_2O_5 ha^{-1} to maize resulted in significantly more nutrient uptake as compared with 0, 30 and 60 kg P_2O_5 ha^{-1} (Arya and Singh, 2000) due to increased dry matter production. These results also corroborate the findings of Sreelatha et al. (2015) and Alam et al. (2018).

The interaction effect of levels and times of Phosphorus application on nitrogen uptake of maize at harvest was not significant during both the years of study

3.2.2. Phosphorus uptake

The data on phosphorus uptake by grain, stover and total uptake due to levels of phosphorus and its application time is presented in Table 3.

The highest phosphorus yield (kg ha^{-1}) in grain, stover and total Phosphorus yield, respectively was recorded with application of 60 kg P_2O_5 ha^{-1} (17.20, 8.49, 25.68 in first year and 16.40, 8.30, 24.71 in second year) over the application of 45 kg P_2O_5 ha^{-1} (15.30, 7.49, 22.79 in first year and 14.60, 7.03, 21.63 in second year) and 30 kg P_2O_5 ha^{-1} (12.51, 5.85, 18.36 in first year and 12.25, 5.70, 17.95 in second year), with significant differences between any two of the phosphorus levels tested in both years. The phosphorus yield (kg ha^{-1}) in grain, stover and total yield was significantly greater with the application of phosphorus at 10 days before harvest of rice (16.06, 7.79, 23.85 during first year and 15.17, 7.38, 22.54 during second year) and as basal application at the time of sowing of maize (15.43, 7.46, 22.89 in first year and 14.81, 7.15, 21.96 in second year) over its application at the time of first irrigation (13.52, 6.58, 20.10 in first year and 13.28, 6.51, 19.79 in second year). The difference in Phosphorus yield between former 2 was not found significant in both years.

The interaction effect of levels and times of Phosphorus application on Phosphorus uptake of maize at harvest was

Table 3: Uptake of Phosphorus by maize as influenced by its levels and time of application

Treatment	Uptake of Phosphorus					
	By Grain (kg ha^{-1})		By Stover (kg ha^{-1})		Total (Grain +Stover) (kg ha^{-1})	
	First year	Second year	First year	Second year	First year	Second year
Factor 1: Phosphorus levels (P)						
P_1: 30 kg P_2O_5 ha^{-1}	12.51	12.25	5.85	5.70	18.36	17.95
P_2: 45 kg P_2O_5 ha^{-1}	15.30	14.60	7.49	7.03	22.79	21.63
P_3: 60 kg P_2O_5 ha^{-1}	17.20	16.40	8.49	8.30	25.68	24.71
SEm±	0.26	0.16	0.14	0.08	0.36	0.20
CD (p=0.05)	0.77	0.49	0.42	0.25	1.09	0.59
Factor 2: Phosphorus application time (T)						
T_1: At 10 days before harvest of rice	16.06	15.17	7.79	7.38	23.85	22.54
T_2: At the time of sowing of maize	15.43	14.81	7.46	7.15	22.89	21.96
T_3: At the time of first irrigation to maize	13.52	13.28	6.58	6.51	20.10	19.79
SEm±	0.26	0.16	0.14	0.08	0.36	0.20
CD (p=0.05)	0.77	0.49	0.42	0.25	1.09	0.59
Interaction (PXT)						
SEm±	0.45	0.28	0.24	0.14	0.63	0.34
CD (p=0.05)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

not significant during both the years of study.

Likewise, application of 90 kg P_2O_5 ha^{-1} to maize resulted in significantly more nutrient uptake as compared with 0, 30 and 60 kg P_2O_5 ha^{-1} (Arya and Singh, 2000). Similar findings in Phosphorus uptake of maize (22.9 and 27.5 kg ha^{-1}) was also recorded with application of 45 and 60 kg P_2O_5 ha^{-1}, respectively over without phosphorus application (Narang et al., 1989). The increase in uptake of Phosphorus by maize at higher levels of Phosphorus was due to increased dry matter production as well as the nutrient concentration grain and stover (Sreelatha et al., 2015, Alam et al., 2018).

3.2.3. Potassium uptake

The data on potassium uptake at harvest by grain and stover as well as the total uptake is presented in Table 4.

Application of 60 kg P_2O_5 ha^{-1} recorded significantly higher uptake (kg ha^{-1}) of potassium in grain (25.92 and 24.38) and stover (45.66 and 44.69), as well as the total potassium uptake (71.58 and 69.07) during two years respectively over that of 30 and 45 kg P_2O_5 ha^{-1}. The differences between the latter two phosphorus levels were also significant.

The potassium uptake was also significantly influenced by phosphorus application time (Table 4). The Potassium uptake (kg ha^{-1}) of maize with application of phosphorus at 10 days before harvest of rice by grain (23.26 and 21.97), stover (42.18 and 40.21) and total uptake (65.44 and 62.19); and at the time of sowing of maize by grain (22.41 and 21.06), stover (41.03 and 39.38) and total uptake (63.44 and 60.49) in both years, respectively was significantly higher over its application at the time of first irrigation. These findings corroborate the finding of Arya and Singh (2000), Sreelatha et al. (2015) and Alam et al. (2018). The increase in uptake of Potassium by maize at higher levels of Phosphorus was due to increased grain and stover yield.

The interaction effect of levels and times of Phosphorus application on Potassium uptake of maize at harvest was not significant during both the years of study.

3.3. Post-harvest soil fertility status

Post-harvest soil fertility status was significantly influenced by both levels and time of application of phosphorus (Table 5).

At the end of crop season significantly lower quantity of soil available nitrogen and potassium was observed at 60 kg P_2O_5 ha^{-1} over that of 45 and 30 kg P_2O_5 ha^{-1} in both years. Whereas, the trend was reverse for the soil available phosphorus.

Application of phosphorus at the time of first irrigation to maize recorded significantly higher quantity of soil available phosphorus over its application at 10 days before harvest of rice or at the time of sowing of maize. However, later two treatments did not record any significant differences between them. Phosphorus application time did not influence the soil available nitrogen and potassium.

The interaction effect of levels and times of Phosphorus application on soil available Nitrogen, Phosphorus and

Table 4: Uptake of Potassium by maize as influenced by levels and time of Phosphorus application

Treatment	By Grain ($kg\ ha^{-1}$)		By Stover ($kg\ ha^{-1}$)		Total (Grain +Stover) ($kg\ ha^{-1}$)	
	First year	Second year	First year	Second year	First year	Second year
Factor 1: Phosphorus levels (P)						
P_1: 30 kg P_2O_5 ha^{-1}	17.31	16.79	34.09	32.36	51.39	49.14
P_2: 45 kg P_2O_5 ha^{-1}	21.77	20.42	41.25	38.54	63.02	58.95
P_3: 60 kg P_2O_5 ha^{-1}	25.92	24.38	45.66	44.69	71.58	69.07
SEm±	0.38	0.24	0.77	0.45	1.05	0.55
CD (p=0.05)	1.13	0.71	2.31	1.35	3.15	1.64
Factor 2: Phosphorus application time (T)						
T_1: At 10 days before harvest of rice	23.26	21.97	42.18	40.21	65.44	62.19
T_2: At the time of sowing of maize	22.41	21.06	41.03	39.38	63.44	60.43
T_3: At the time of first irrigation to maize	19.32	18.54	37.80	36.00	57.12	54.54
SEm±	0.38	0.24	0.77	0.45	1.05	0.55
CD (p=0.05)	1.13	0.71	2.31	1.35	3.15	1.64
Interaction (PXT)						
SEm±	0.65	0.41	1.34	0.78	1.82	0.95
CD (p=0.05)	N.S.	NS	N.S.	N.S.	N.S.	N.S.

Table 5: Soil available nutrients after harvest of maize as influenced by levels and time of Phosphorus application

Treatment	Nitrogen ($kg\ ha^{-1}$)		Phosphorus ($kg\ ha^{-1}$)		Potassium ($kg\ ha^{-1}$)	
	First year	Second year	First year	Second year	First year	Second year
Factor 1: Phosphorus levels (P)						
P_1: 30 kg P_2O_5 ha^{-1}	195.42	198.70	16.78	16.08	197.11	202.36
P_2: 45 kg P_2O_5 ha^{-1}	192.58	195.83	17.72	17.71	190.61	195.20
P_3: 60 kg P_2O_5 ha^{-1}	188.30	191.40	18.45	19.24	185.73	190.23
SEm±	1.03	0.79	0.06	0.06	0.82	0.85
CD (p=0.05)	3.10	2.36	0.18	0.19	2.45	2.54
Factor 2: Phosphorus application time (T)						
T_1: At 10 days before harvest of rice	190.94	194.19	17.45	17.33	190.23	194.79
T_2: At the time of sowing of maize	191.68	194.96	17.61	17.51	190.93	195.52
T_3: At the time of first irrigation to maize	193.68	196.77	17.89	18.17	192.29	197.49
SEm±	1.03	0.79	0.06	0.06	0.82	0.85
CD (p=0.05)	N.S.	N.S.	0.18	0.19	N.S.	N.S.
Interaction (PXT)						
SEm±	1.79	1.37	0.10	0.11	1.42	1.47
CD (p=0.05)	N.S.	N.S.	N.S.	NS	N.S.	N.S.

Potassium after maize harvest was not significant during both the years of study.

These results are accordance with the findings of Eckert and Johnson (1985), Narang et al. (1989), Howard et al. (2002) and Singh et al. (2007). The decrease in soil available nitrogen and potassium at higher levels of phosphorus might be credited that more availability of Phosphorus appears to have promoted root growth and its proliferation triggering in greater removal of available nitrogen and potassium. While added phosphorus helped for restoration of soil fertility (Choudhary et al. (2017).

Similar findings of more dry matter, increased uptake and less soil available phosphorus with application of Phosphorus at 10 days before sowing or at the time of sowing of maize as compared to late (15 DAS) application of Phosphorus was also reported by Amanullah et al. (2010b). They stated that poor growth was noticed by with latter treatment was due to more sorption of native Phosphorus and less availability because of clay loam soil texture as well as delayed Phosphorus application. Bharathi and Subba Rami Reddy (2010) also reported similar findings in rice fallow zero till maize with recommended dose of phosphorus

Increased Phosphorus sorption following drainage is likely to be a cause of low native Phosphorus supply to maize following rice. It is a process of formation of poorly crystalline amorphous iron hydroxides, with high Phosphorus sorption capacity, which lead to increased sorption of native Phosphorus (Willett et al., 1988). This process (sorption) depend on flood–drain cycles, temperature, soil texture, organic matter content and the content of reducible Fe (Sah et al., 1989). In the present investigation delayed application of Phosphorus upto first irrigation to maize resulted in lower growth parameters due to lower availability of native Phosphorus due to sorption, which is needed initially for better growth and proliferation of roots.

3.4. Monetary returns

Both, levels and time of application of phosphorus significantly influenced the gross and net monetary returns and benefit: cost ratio (Table 6).

Table 6: Monetary returns of maize as influenced by levels and time phosphorus application

Treatment	Gross returns (₹ ha^{-1})		Net returns (₹ ha^{-1})		B:C ratio	
	First year	Second year	First year	Second year	First year	Second year
Factor 1: Phosphorus levels (P)						
P_1: 30 kg P_2O_5 ha^{-1}	34666	37645	18694	21841	1.17	1.38
P_2: 45 kg P_2O_5 ha^{-1}	39668	42095	23358	25953	1.43	1.61
P_3: 60 kg P_2O_5 ha^{-1}	43771	45012	27124	28533	1.63	1.73
SEm±	662	448	662	448	0.04	0.03
CD (p=0.05)	1986	1344	1986	1344	0.12	0.08
Factor 2: Phosphorus application time (T)						
T_1: At 10 days before harvest of rice	41563	43002	25253	26861	1.55	1.66
T_2: At the time of sowing of maize	40154	42395	23936	26346	1.47	1.64
T_3: At the time of first irrigation to maize	36388	39355	19987	23122	1.22	1.42
SEm±	662	448	662	448	0.04	0.03
CD (p=0.05)	1986	1344	1986	1344	0.12	0.08
Interaction (PXT)						
SEm±	1147	777	1147	777	0.07	0.05
CD (p=0.05)	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

Application of 60 kg P_2O_5 ha^{-1} fetched significantly more amount of gross monetary returns (₹ 43771 ha^{-1} and ₹ 45012 ha^{-1}), net monetary returns (₹ 27124 ha^{-1} and ₹ 28533 ha^{-1}) and benefit cost ratio (1.63 and 1.73) over that of 45 kg P_2O_5 ha^{-1} and 30 kg P_2O_5 ha^{-1} in first and second years, respectively. Application of 60 kg P_2O_5 ha^{-1} gave additional net returns of ₹ 3766 and ₹ 8430 ha^{-1} in first year, and ₹ 2580 ha^{-1} and ₹ 6692 ha^{-1} in second year over the application of 45 kg P_2O_5 ha^{-1} and 30kg P_2O_5 ha^{-1}, respectively.

Among time of phosphorus applications, application of phosphorus at 10 days before harvest of rice recorded statistically similar gross monetary returns of ₹ 41563 ha^{-1} and ₹ 43002 ha^{-1}, net monetary returns of ₹ 25253 ha^{-1} and ₹ 26861 ha^{-1} and benefit cost ratio of 1.55 and 1.66 with its application at the time of sowing of maize crop, which gave gross monetary returns (₹ 40154 ha^{-1} and ₹ 42395 ha^{-1}), net monetary returns (₹ 23936 ha^{-1} and ₹ 26346 ha^{-1}) and benefit cost ratio (1.47 and 1.64) in first and second years, respectively (Table 6). However both these treatments were found superior to its delayed application along with first irrigation to maize. Additional net returns (₹ ha^{-1}) of 5266 and 3949 in first year, and 3739 and 3224 in second year were realized with these treatments over delayed application of phosphorus.

The results of field experiments from medium Phosphorus soils also in accordance with these findings and revealed that the significant response to applied phosphorus on gross and net monetary returns and benefit: cost ratio of *kharif* maize was up to 60 kg P_2O_5 ha^{-1} (Choudhary et al. (2017). These results are close conformity with those of Jat et al. (2012), Sreelatha et al. (2015), Kumar et al. (2018) and Shyam et al., 2021.

Similarly, Bharathi and Subba Rami Reddy (2010) reported that significantly higher benefit: cost ratio (1.31) was recorded with the application of recommended dose of single super phosphate before harvesting of the paddy crop compared to its application as slurry 15 days after dibbling of maize seed.

These findings suggest that the application of 60 kg P_2O_5 ha^{-1} at 10 days before harvest of rice or at the time of sowing of maize is required for sustainable and higher yields of maize in rice-zero till maize cropping system.

4. Conclusion

Application of 60 kg P_2O_5 ha^{-1} to maize either at 10 days before harvest of rice or at the time sowing of crop were found equally efficient, sustainable and fetched significantly higher yields thereby superior monetary returns than its delayed application at the time of first irrigation to no-till maize after *kharif* rice. Rice-maize is one of the widely adopted cropping systems under limited water resources and cultivation of maize under no-till conditions is gaining momentum.

5. Further Research

The nutrient dynamics and sustainability of the system on a long run needs to be evaluated especially the phosphorus sorption, release and uptake patterns needs to be investigated under varied soil conditions of low, medium and high available phosphorus status vis a vis its balance in the soil. During dry season, the role of Phosphorus solubilizing bacteria (PSB) may be verified in augmenting ‘Phosphorus’ in available form to no-till maize.

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