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Evaluating the effect of phosphatic fertilizers on soil and plant P availability and maximising rice crop yield

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ABSTRACT

A laboratory experiment was taken up to evaluate the effects of P sources viz., Mussoorie rock phosphate (MRP), single super phosphate (SSP) and complex fertilisers (20:20:0 and 15:15:15) on availability and release pattern of P for a duration of 60 days in two sets of samples from soils of low and high status of available P from the rice dominant tracts of Vadipatti block of Madurai district. Among the treatments imposed, SSP and FYM incubated soils registered maximum release of Olsen - P of 163.3 and 184.3 mg kg $^{-1}$ in soils of low and high available P status respectively. A field experiment was taken up in the farmers field at Irumbadi village of Vadipatti block of Madurai district during rabi 2013 with rice (var ADT 39) as test crop to evaluate the influence of P sources and forms (SSP and complex P with and without PSB) on soil nutrient status, uptake and crop yield. Among the P sources, 20:20:0 and PSB followed by 20:20:0 alone proved significantly superior to SSP and farmer's fertilizer practice of DAP application. It was noteworthy to observe that 100 % and 50 % of recommended P as SSP were on par in influencing the available P status and yield of rice crop indicating the scope for reducing 50 % of P in soils of high P availability.

Key words: *Phosphorus, fertilizer source, P availability, uptake, yield and rice*

INTRODUCTION

Phosphorus is the eleventh most abundant element in the earth's crust and only a small percentage is present in high enough concentrations to be utilized by humans for producing fertilisers and other products (Smil, 2000; Millennium Ecosystem Assessment, 2005). The introduction of mineral phosphorus fertiliser enabled the phosphorus which is lost from the soil when crops are harvested (Cordell et al., 2009). Looking at the global path of phosphorus from 'mine to fork' the efficiency seems low; only around one fifth of the phosphorus mined for fertiliser production is in the end consumed by the human population (Cordell et al., 2009). Restrictions on the use of fertilisers are usually motivated by the negative impacts of excessive uptake in agriculture rather than by the threat of a possible shortage in future.

More efficient utilization of phosphorus is necessary but will not alone be sufficient to make global agriculture sustainable. However, most of the discussion about efficient phosphorus use, and most of the measures to achieve this, have been motivated by concerns about toxic algal blooms caused by the leakage of phosphorus and nitrogen from agricultural land (Sharpley et al., 2005). While such measures are essential, they will not by themselves be sufficient to achieve phosphorus sustainability. Further, recent research investigations on P availability status and results of long term manure - fertilizer experiments in most of the agricultural institutes, research stations of the state and the country have reported higher status of available P and thus only require light applications to replace what is lost in harvest.

This understanding and experience has led to an attempt through the present investigation to highlight the need for efficient utilization of mineral fertilisers and encourage farmers to use P fertilisers according to the need of the crop after assessing the actual nutrient status of the soil. Total soil P is often 100 times higher than the fraction of soil P available to crop plants. The range of fertiliser P recovery by rice crop varies between 10 and 20 % of applied P. So the balance amount (80-90 %) remains in the soil in less available form (Deb, 2009).

Rice is mostly grown under submerged conditions, but in areas where the irrigation water is scarce, rice growers resort to alternate flooding and drying (Kumar et al., 2017) and P fixation is significantly greater under alternate flooding than that under continuous flooding. Apart from adoption of modern scientific cropping sequences (Roy et al., 2011; Kumar et al., 2016) for sustainable agriculture, a nutrient management approach should be based on integrated use of organic and inorganic sources for maintaining soil quality. Phosphorus fixation under alternate flooding and drying conditions has been studied by various researchers and it has been shown that P applied to the soil during a flooding and drying sequence is immobilized (Smith,1969; Simpson and Williams, 1970) and P availability has been found to decrease within 7 days of flooding because of the transfer of P from an aluminum to an iron phosphate during the period of flooding.

Soil based P management requires a long term management strategy to maintain soil available P supply at an appropriate level through monitoring soil P fertility because of the relative stability of P within soils. By using this approach, P fertiliser application can be generally reduced by 20 % compared to farmer's practice for high yielding cereal crops like rice (Zhang et al., 2010). This may be of significant importance for saving P resources without sacrificing crop yields though it may cause P accumulation in soil due to high threshold levels and low use efficiency by crops (Shen et al., 2011). Application of biofertilizers like PSB (phosphate solubilizing bacteria) and VAM (Vesicular arbuscular mycorrhizae) along with inorganic P fertilizers is advantages as they help in solubilizing the native as well as applied P, thereby reducing P fixation and increased availability to plants leading to highest grain yield and uptake of N and P by crops (Sarawgi et al., 2012).

Hence, in the present study the efficacy of different sources of P fertilizer were evaluated in terms of sustaining the soil availability status, enhancing the use efficiency and maximising the yield of rice crop in the predominant rice growing regions.

MATERIALS AND METHODS

Incubation experiment

Incubation experiment was conducted in the post graduate research laboratory of the Department of Soils and Environment at Agricultural College and Research Institute, Madurai, Tamil Nadu for a duration of 60 days. Representative surface (0 -15) soil samples from 26 villages of Vadipatti block were collected, processed and analysed for the status of P availability. Based on the analytical results, these soils were categorized into low (<11 kg ha^{-1}) and high (>22 kg ha^{-1}) status of P availability. Details of the location of collection and categorization of soil samples for conducting the laboratory incubation study are furnished in Table 1 and 2.

Laboratory incubation study to evaluate the P release pattern was carried out with two sets (low and high available phosphorus) of soils were maintained for the incubation study over a period of 60 days. Two hundred grams of soil was used for each experimental unit and the incubation was carried out in 500 ml plastic storage containers. Each treatment combination was incubated maintaining the maximum moisture content at field capacity (21 % gravimetrically) under laboratory conditions. Soil samples were drawn at weekly intervals and analysed for Olsen-available P.

The treatments were imposed based on the fertiliser recommendation *viz.*, 150:50:50 Kg N, P_2O_5,

Table 1. Details of predominant rice growing villages of Vadipatti block of Madurai district

1.	Aandipatti	14.	Kuruvithurai
2.	Bodhinayackanpatti	15.	Mannadimangalm
3.	Cheminipatti	16.	Manickampatti
4.	Chinnamanayackanpatti	17.	Naachikulam
5.	Chitthalankudi	18.	Nedungulam,
6.	C.Pudhur	19.	Poochampatti
7.	Irumbadi	20.	Ramayanpatti
8.	Kacchakatti	21.	Sukkampatti
9.	Kaadupatti	22.	Thatthampatti
10.	Kattakulam	23.	Thiruvedagam
11.	Karupatti	24.	Thumbichampatti
12.	Kulasekarankottai	25.	T.V.Nallur
13.	Kutladampatti	26.	Viralipatti

Table 2. Details of location of soils of low and high P availability chosen to conduct incubation experiment

S.No.	Low P available regions	High P available regions
1.	Viralipatti	Kattakulam
2.	Karupatti	Nachikulam
3.	Manickampatti	Kattakulam West
4.	Kacchakatti	Sukkampatti
5.	Irumbadi	South Irumbadi

K_2O ha^{-1}, Mussoorie rock phosphate @ 224 kg ha^{-1}, farm yard manure with the nutrient content of 0.5, 0.25 and 0.4 per cent of nitrogen, phosphorus and potassium respectively was applied @ 12.5 tonnes ha^{-1} and phosphate solubilizing bacteria (Lignite based phosphate solubilizing bacterium, *Bacillus megaterium* var. Phosphaticum PSB-1, Source: Department of Agricultural Microbiology, AC and RI, Madurai, TNAU, Tamil Nadu.) as soil application @ 2 kg ha^{-1} after the application of inorganic fertilizer sources in a completely randomized design (CRD) replicated thrice with the treatment details furnished below. T_1: Complex fertilizer source (20:20:0); T_2 : Complex fertiliser source (20:20:0) + Phosphorus solubilizing bacteria; T_3: Mussoorie rock phosphate + Phosphorus solubilizing bacteria; T_4: Farm yard manure + Straight fertilizer source (Single super phosphate); T_5: Straight fertilizer source (Single super phosphate); T_6: Control (No fertilizer).

Field experiment

A field experiment was taken up in the farmer's field at Irumbadi village of Vadipatti block of Madurai district during *rabi* 2013 with rice (var. ADT 39). The experimental soil was neutral to slightly alkaline, non - saline with moderate status of organic carbon and available N and high status of available P and K. Ten treatments (T_1: 100% recommended P as SSP (313 kg SSP ha^{-1}); T_2: 50% recommended P as SSP (156.25 kg SSP ha^{-1}); T_3: T_1 + PSB @ 2 kg ha^{-1} ; T_4: T_2 + PSB @ 2 kg ha^{-1} ; T_5: Complex fertiliser source 15:15:15 (On P equivalent basis); T_6: Complex fertiliser source 20:20:0 @ 250 kg ha^{-1} (On P equivalent basis); T_7: T_5 + PSB @ 2 kg ha^{-1} ; T_8: T_6 + PSB @ 2 kg ha^{-1} ; T_9: Farmer's fertiliser practice (315 kg Urea; 250 kg complex; 150 kg DAP as basal and 100 kg MOP ha^{-1}); T_{10}: Control (No fertilizer)) were imposed with three replications in a randomized block. N, P_2O_5 and K_2O @ 150:50: 50 kg ha^{-1} were applied as urea, single super phosphate and muriate of potash in T_1,T_2, T_3 and T_4 and 50 kg K_2O as MOP in T_6. Samples at regular intervals (critical crop growth stages) were collected and plant phosphorus concentration were assessed by following vanadomolybdate yellow colour method (Jackson, 1973), dry matter yield of the crop was recorded and percentage of plant P uptake was calculated by multiplying the dry matter yield with its nutrient content of rice crop.

The soil samples collected for both incubation and field experiments were processed and used for analysis. The samples were air dried, powdered and sieved through 2.0 mm sieve for the analysis of basic parameters like pH, electrical conductivity and available nitrogen was analyzed by alkaline permanganate method (Subbiah and Asija, 1956), available phosphorus by Olsen et al. (1954) method and available potassium by ammonium acetate method (Toth and Prince, 1949). For estimating organic carbon the samples were sieved through 0.5 mm sieve separately by adopting standard procedures. Grain yield was determined from each plot and adjusted to the standard moisture content of 0.14 g H_2O g^{-1} fresh weight (Kumar et al., 2017).

RESULTS AND DISCUSSION

Nutrient release pattern and availability of Phosphorus (mg kg^{-1}) during the incubation

It is quite apparent from the study that the P release patterns of soils treated with P fertilizers were significantly higher than the untreated control soils and continued to decrease gradually during the course of incubation period (1 - 60 days). The decrease was from a mean available P content of 86.2 and 94.8 mg kg^{-1} in the first week of incubation period to 69.89 and 78.99 mg kg^{-1} in the ninth week of incubation period in the soils of low (Fig. 1) and high (Fig. 2) available P status, respectively. This was observed to be a common behavior of P under most situations as already been reported by Begum et al. (2004) and Sharma et al. (2003). The subsequent decrease of available P at later stages of incubation might be due to read sorption or fixation of P. Fertilizer P tends to be fixed soon after application and becomes mostly unavailable, resulting in low recovery and a considerable P accumulation in soils (Richardson, 1994). Among the treatments imposed, SSP and FYM incubated soils registered the maximum release of available P content of 163.3 and

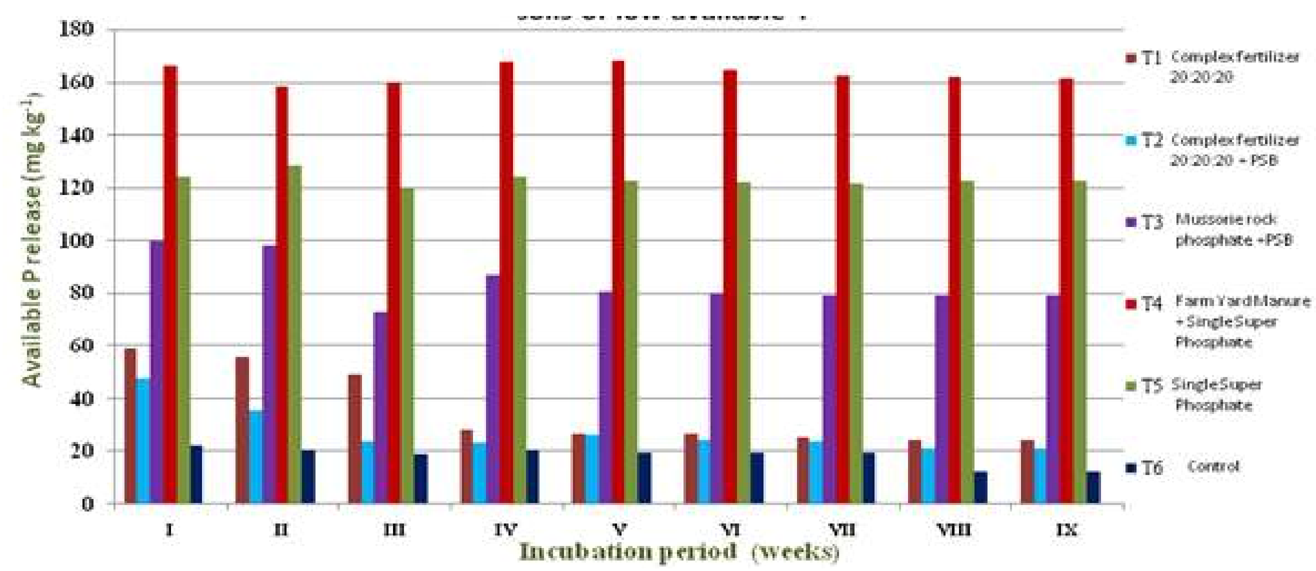

Fig. 1. Availability of phosphtus (mg kg^{-1}) during the incubation period in soils of low available P

184.3 mg kg^{-1}in soils of low and high available P status, respectively. The P supplying power of the soils was found to be higher in soils of high availability compared to the soils of low availability. An increase of available P in the first few weeks and a gradual decrease during later weeks were reported in almost all the treatments during the course of incubation which could be attributed to the physicochemical mobilization of P into soluble forms. The improvement in the soil available P with FYM addition could be attributed to many factors, such as the addition of P through FYM, and retardation of soil P fixation by organic anions formed during FYM decomposition (Ali et al., 2009). Addition of FYM along with inorganic fertilisers which stimulated the growth and activity of microorganisms, they participate in the biological cycling of elements and transformation of the mineral compounds and thus increases the availability of P in soil (Udayakumar and Santhi, 2016 and 2017). A significant improvement in available P status was also noticed with inoculation of PSB with Mussoorie

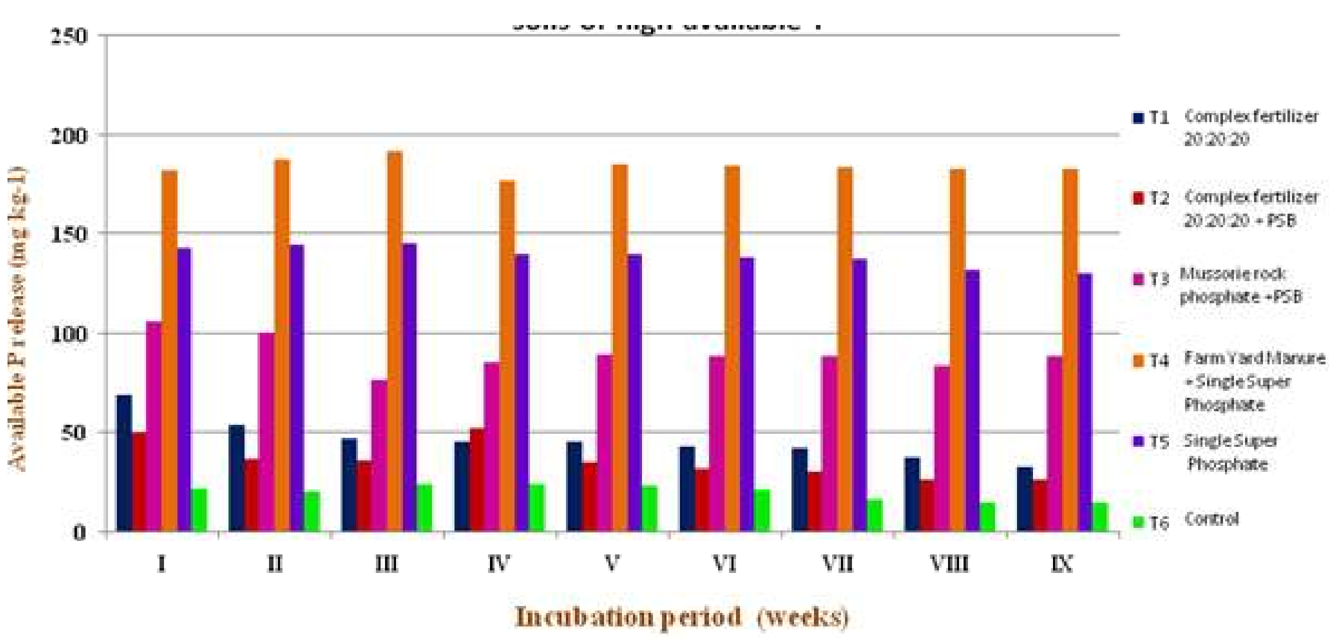

Fig. 2. Availability of phosphtus (mg kg^{-1}) during the incubation period in soils of high available P

rock phosphate (MRP) (123.1 and 138.6 mg kg^{-1}) in soils of low and high available P status, the observation of which was in accordance with those of Tarafdar et al. (2008). This might be attributed to the capability of phosphate solubilising bacteria (PSB) to convert unavailable apatite P to available forms as reported by Sharma et al. (2003).

Soil available phosphorus

Addition of P fertilizers in the soils of high P status recorded significantly higher available P status during various growth stages of rice crop and in post-harvest soil compared to unfertilized control. Among the P sources, 20:20:0 and PSB (T_8) followed by 20:20:0 alone (T_6) proved significantly superior to SSP and farmer's fertiliser practice of DAP application. The water soluble P_2O_5 (12 %) from this fertiliser source has contributed significantly to the labile pool of P thus maximising the available P status in the soil. Further, the citrate soluble P_2O_5 (8 %) of complex source which might have effectively solubilised by the applied phosphate solubilisers contributed to much of soluble phosphates for the plant uptake (Pattanayak et al., 2009). Also, the availability of P was higher in this treatment at tillering, flowering and harvest stages with 28.9, 28.3 and 27.5 kg ha^{-1}, respectively due to adequate macro nutrients and smaller quantities of microelements present in balanced proportions in the complex fertiliser source thus enhancing the use efficiency especially phosphorus.

Soils vary in their sorption capacity for phosphorus due to their difference in pH, presence of complexing anions, clay content (Fuller et al., 1985) and organic carbon (Das et al., 2002). The experimental soil with neutral pH and less amount of clay and moderate amount of organic matter is said to have lower maximum phosphorus buffering capacity. This fact was very well established in the analytical results where 50 and 100 % recommended P as SSP were on par with each other in influencing the available P status in soils recording 23.7 and 23.9 kg ha^{-1}, respectively. However, the effect of PSB was not much significant on SSP in influencing the P availability status. It was noteworthy to observe that complex fertilizer sources (20:20:0 and 15:15:15) were on par in influencing the available P status indicating the scope for reducing 50 % of P when combined with phosphate solubilisers in soils of high P availability. The maximum available P (28.5 kg ha^{-1}) recorded in treatments with PSB's may be due to the mobilization of soil P by the acidification of soil (Deubel et al., 2000), the release of enzymes such as phosphatases and phytases of carboxylates such as gluconates and oxalates (Jones and Oburger, 2011) which dissociates the bound forms of phosphates like $Ca_3(PO_4)$. Hence, the findings of the study highlights the possibility of reduction of P fertiliser use with the application of PSB's and also under high status of total P in wetland rice cultivation. Similar observations have been reported by Thakuria et al. (2004) and Hossain et al. (2008).

Grain and straw yields of rice crop

Rice grain and straw yields were significantly influenced by the application of different phosphatic fertilizers.

Table 3. Available phosphorus status of soils and plant at various stages of rice crop

Treatments	Soil Available phosphorus (kg ha^{-1})			Total Phosphorus (%)			
	Tillering	Flowering	Post Harvest	Tillering	Flowering	Grain	Straw
T_1	24.28	24.00	23.53	0.405	0.249	0.058	0.047
T_2	23.98	23.78	23.21	0.396	0.232	0.042	0.036
T_3	24.32	23.86	23.79	0.439	0.334	0.049	0.038
T_4	23.86	23.80	22.95	0.367	0.149	0.038	0.029
T_5	25.53	24.99	23.86	0.421	0.317	0.061	0.058
T_6	26.36	26.03	24.98	0.324	0.310	0.070	0.064
T_7	26.00	25.43	24.00	0.444	0.343	0.068	0.061
T_8	28.89	28.32	27.53	0.457	0.402	0.074	0.069
T_9	24.00	23.83	23.56	0.249	0.156	0.028	0.013
T_{10}	21.99	21.86	20.72	0.166	0.134	0.012	0.008
Mean	24.82	24.39	23.60	0.364	0.253	0.050	0.042
SED	0.463	0.542	0.442	0.055	0.009	0.001	0.0006
CD	0.974	1.139	0.929	0.116	0.019	0.002	0.001

The results showed that integrated application of complex fertilizer source (15:15:15 or 20:20:0) and soil application of PSB (2 kg ha^{-1}) showed higher response than the application of complex fertilizer sources alone. It was found that application of ammonium nitro phosphates (20:20:0) @ 150:50 kg N, P_2O_5 and 50 kg K_2O ha^{-1} as MOP and PSB (2 kg ha^{-1}) recorded the highest mean grain yield (6950 kg ha^{-1}) followed by nitrophosphate complex with potash (15:15:15) @ 150:50:50 kg N, P_2O_5 and K_2O ha^{-1} and PSB (2 kg ha^{-1}) that recorded a mean grain yield of 6135 kg ha^{-1}. The increase of grain yield with the soil application of P solubilising microorganisms may be due to increase in P availability through solubilisation of insoluble or citrate soluble inorganic phosphates in soil / fertilizers, decomposition of phosphate rich organic compounds and production of plant growth promoting substances (Gaur and Sunita, 1999). Plant root associated phosphate solubilising bacteria (PSB) could be possible partial substitutes for inorganic P fertilisers for promoting plant growth and yield (Vikram et al., 2007). However, the efficiency of PSB's was not very much prominent when applied in combination with SSP. These SSP sources (100% and 50% of recommended P) with or without PSB (T_1, T_2, T_3 and T_4) were on par with each other in influencing the grain yields of rice crop. Hossain et al. (2008) reported that the bacterium in combination with rock phosphate and other citric acid soluble P sources produced the desired effect more prominently than when bacterium applied in combination with SSP. The grain yields on soil inoculated PSB treatments along with complex sources (T_7 and T_8) recorded 66 per cent increase in yield over control. The water soluble SSP (100 and 50% of recommended P) were equally effective in increasing the grain yields of rice. The results are in consonance with the findings of Ravi and Siddaramappa (2002) who reported the superiority of rock phosphate over SSP in influencing the grain yields of rice. The on par effect of 100 and 50 % SSP on grain yields of rice crop (Var. ADT 39) in the rice dominant tract of Madurai district showed the possibility of reduction (30-50%) in the use of P fertilizer in soils of long term use of inorganic P fertilizers and soils generally reporting high available P status. Thakuria et al. (2004) from their experiments concluded that a significant reduction in the use of P fertilizer could be achieved if solubilisation of soil insoluble P is made available to crop plants.

Hence, the present experimental results proved that integrated application of recommended dose of complex fertilizer sources (20:20:0 or 15:15:15) @ 150:50:50 kg N, P_2O_5, K_2O ha^{-1} along with PSB @ 2 kg ha^{-1} recorded the maximum grain and straw yields of rice crop. This is in accordance with the findings of Yadav and Dadarwal, 1997 who reported that seed or soil inoculation with PSB improved solubilisation of fixed soil P and applied phosphates resulting in higher crop yields. The results also showed that based on P recovery and influence on crop yield, the fertilizer sources can be arranged in the order RCF - Ammonium nitro phosphate (20:20:0) > RCF nitro phosphate with potash (15:15:15) > complex and DAP> SSP. The citrate soluble materials with complex fertilizer sources facilitated slow and steady release of P along with soil inoculation of P solubilizing bacteria, thus increasing the soil solution P concentration favouring enhanced nutrient uptake compared to that of other forms of fertilizers. The increased uptake of nutrients due to the presence of P solubilisers was also reported by Sharma and Dayal (2005). Similar trend of influence was observed on the yield of rice straw in the present experiment. The percent straw yield increased over control was significantly influenced by the application of various fertilizer sources (Table 4). Straw yield increased 50 % when applied with 20:20:0 and 50 kg K_2O ha^{-1} along with PSB @ 2 kg ha^{-1} and it was 46 % when applied with 15:15:15 and PSB @ 2 kg ha^{-1}. Phosphorus application to rice through SSP increased P accumulation but did not consistently increase grain and straw yields in these treatments because flooding decreased soil P sorption and increased P diffusion as reported by Hussain and Yasin (2004).

Total phosphorus content and uptake

The total P content at different stages of rice crop *viz.*, tillering, flowering and harvest and its uptake was influenced by the application of various sources and forms of fertilisers. Application of ammonium nitro phosphate complex, 20:20:0 along with PSB and recommended dose of K @ 50 kg ha^{-1} recorded significantly higher P content of 0.457 % at tillering, 0.402 % at flowering and 0.074 and 0.069 % with regard to grain and straw content at harvest stage respectively. The water soluble fraction of P in ammonium nitro phosphate acts as a starter dose and

Table 4. Yield and phosphorus uptake of rice crop.

Treatments	Yield (kg ha^{-1})		P uptake (kg ha^{-1})	
	Grain	Straw	Grain	Straw
T_1	5210	7200	2.25	2.91
T_2	5143	7169	2.16	2.22
T_3	5280	6423	2.58	2.06
T_4	5176	6182	2.36	2.50
T_5	5720	7180	3.48	3.58
T_6	6052	7614	4.23	4.13
T_7	6135	7418	4.05	3.85
T_8	6950	8120	4.28	4.60
T_9	5247	6967	1.46	0.77
T_{10}	3078	4123	0.48	0.36
Mean	5437	6839	2.79	2.60
SED	21.33	198.6	0.06	0.02
CD	44.18	417.2	0.13	0.05

*Values in each column are mean of three replication. *Recommended N, P_2O_5 and K_2O @ 150:50: 50 kg ha^{-1}were applied as Urea , Single Super Phosphate and Muriate of Potash in T_1, T_2, T_3 and T_4 and 50 kg K_2O as MOP in T_6. *50 kg of K_2O as MOP in T_6.

insoluble P fraction (citrate soluble P) solubilised by PSB proved to be more efficient in increasing the P contents of the rice crop compared to that of SSP and DAP. The importance of adequate tissue P concentrations during early season growth has been reported in many different crop species (Grant et al., 2001). The decrease in P content with the advancement of crop growth might be attributed to the distribution of the initially adsorbed P over a greater amount of dry matter and also due to the decrease in rate of adsorption after tillering stage. Similar findings were reported by Islam et al. (2008).

The total above ground average phosphorus accumulation for rice crop grown under conventional practices is 12.69 kg ha^{-1} (Barison, 2002) and also modification of management practices could enhance plant P uptake by 66 %. The P content in grain and straw in the present investigation varied from 0.012 to 0.074 % and 0.008 to 0.069 % respectively. Among the treatments, nitro phosphates with potash and ammonium nitro phosphates aided with PSB facilitated higher P content and uptake in grain and straw. The uptake pattern of P was directly influenced by the yield of grain and straw. The highest P uptake in rice grain (4.28 kg ha^{-1}) and straw (4.60 kg ha^{-1}) was observed with the application of N and P (150:50 kg ha^{-1}) through complex fertilisers and K through MOP (50 kg ha^{-1}) along with PSB (2 kg ha^{-1}) resulting in a total P uptake of 8.88 kg ha^{-1} and was significantly higher over other treatment combinations. Higher total uptake of P in the above treatments was the combined effect of higher nutrient content in the plant as well as total biological yield as evidenced by the findings of Singh and Ganguly (2005). The uptake of P by grain and straw in treatments T_1 and T_2 (100% and 50% SSP, respectively) were on par with each other necessitating optimization of P input management to improve P use efficiency in rice. Zhang et al. (2010) has reported similar observation in North China plain stating that the P fertiliser application can generally be reduced by 20 % compared to farmer's practice for high yielding cereal crops like rice. The requirement of P was well fulfilled with the application of P solubilisers which would have solubilised the insoluble form of P during its decomposition. These findings were in accordance with the results of Gaur (1990), Hussain (2008) and Kabir et al. (2011). The P uptake in many crops is improved by associations with arbuscular myccohrhizal fungi, particularly in low P soils. The long term use of commercial fertilizers has increased the plant - available soil P of many agricultural soils to excessive levels. Therefore, the rate of P uptake is related to the P concentration in soil solution (Grant et al., 2001).

CONCLUSION

The incubation study and field experiment conducted to evaluate the different sources of phosphatic fertilisers on rice crop yield showed that application of recommended dose of fertilisers (RDF) @ 150:50:50 kg N, P_2O_5 and K_2O ha^{-1} through complex fertiliser (20:20:0) along with phosphate solubilising bacteria (PSB) @ 2 kg ha^{-1} recorded the maximum grain and straw yields. Application of 100 % recommended P as SSP and 50 % recommended P as SSP were on par in influencing the available P status and also the yields of rice crop. Hence, in rice growing soils with high available P status, a maintenance dose of 50 % recommended P as SSP is sufficient to sustain the P fertility status of soil until the soil test values report moderate to low available P. It can be thus concluded that the use of complex fertiliser sources (20:20:0 or 15:15:15) along with PSB @ 2 kg ha^{-1} can be recommended for release and mobilization of insoluble and fixed forms of P and subsequently for maximizing the grain and straw yields of rice crop in the predominant rice growing tracts.

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