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PHOSPHORUS MANAGEMENT IN RICE AND RICE BASED CROPPING SYSTEMS - A REVIEW

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ABSTRACT

In general, the response of lowland rice to phosphorus application is usually lower than that of other dryland crops including upland rice, primarily because of increased solubility of native P in flooded soils. In the rice-wheat cropping system there is little residual effect of P applied to rice on succeeding wheat crop, whereas rice benefits considerably from the application of P to the preceding wheat crop. Judicious combination of soluble source of P combined with Mussoorie rock phosphate can give better performance, as against the conventional source of P alone in several cropping systems. Application method can offset the effects of P-fixation by soils and increase P-efficiency. Fertiliser placement helps overcome fixation in irrigated upland crops. However for rice, surface application or broadcast and mixing it by puddling was best as it resulted in greater P availability. Split application of phosphorus may be useful in cases where initial supply of the nutrient is sufficient to meet the early requirements of the crops. Addition of organic manures and biofertilisers (Phosphobacteria) along with inorganic P application increased the yield levels considerably, besides maintaining the soil health.

Phosphorus is one of the three major nutrients required in crop nutrition, the other two being N and K. Phosphorus plays many vital roles in crop growth. Hasan (1996) reported that for available P in Indian soils, 49.3 per cent of the districts are in low category, 48.8 per cent are medium and 1.9 per cent in the high P category. Nearly 98 per cent of the soils in India are in need of phosphorus for better crop productivity. The response of crops to phosphorus application may differ with the crop ecosystem. The requirement of phosphorus by rice is not as high as that of nitrogen but deciding its dose, time and method of application is very much essential for increased response to applied phosphorus. The deficiency of P and K increases as the fertilizer use has grossly imbalanced ratios of N:P:K. For instance in 1995-96 in Haryana, NPK ratio was 186:42:1 whereas ideal NPK ratio is 4:2:1 (Kanwar and Sekhon, 1998).

Rice cultivation in the rainfed environment is mostly characterized by monocropping, whereas input-intensive cropping systems involving cereals, pulses, oil seeds, tuber and fibre crops are practices under irrigated conditions (Sharma, 1995). Although, many rice-based cropping systems are practised in different agro-climatic regions, the most common ones in India are rice-rice, rice-wheat, rice-wheat-jute, rice-pulse and rice-oilseeds and among these systems rice-wheat contributed 25% of the total food grain production followed by rice-rice (5%) (Kanwar and Sekhon, 1998).

PHOSPHORUS MANAGEMENT CONSIDERATION

Efficiency of phosphatic sources : Most common practice to supply phosphorus to crops is in the form of water soluble chemically processed phosphatic fertilizers. Due to high cost of chemically processed fertilizers and due to possibility of more soluble P getting locked up in amorphous clay system, less soluble and less expensive rock phosphate is preferred source of P in low pH soils (Minhas and Kick, 1974). Judicious combination of soluble source of P combined with Mussoorie rock phosphate (MRP) can give better performance, as against the conventional source of P-alone, in several cropping system. Diammonium phosphate (DAP) is the major source of P in rice-wheat systems, accounting for nearly 85% of the P used together with single super phosphate (SSP) (Abrol and Meelu, 1998). Studies in different locations in rice-rice cropping system indicated that rock phosphate (RP) and combination of SSP and RP in 1:2 ratio are as good as water soluble sources like SSP and DAP in acidic soils of Jorhat. In Chiplima and Bhubaneswar, ammonium polyphosphate (APP) has also showed good promise in acidic soils. In neutral soil at Bhavanisagar, all the water soluble P sources were equally effective. In alkaline soil at Sirguppa, Phospal [a senegalese calcined calcium aluminium phosphate containing 34% total P_2O_5 of which 80% is citrate soluble form] was found to be a promising P source which proved better than SSP. Response to applied P varied greatly from location to location and had apparently no relation with the available P-status of soils (Hegde, 1992).

In acidic soil (pH 5.7) in Karnataka, maton rock phosphate (32.6% P_2O_5) and 25% acidulated maton rock phosphate (MTRP) recorded 7.8% and 15.68% increase in yield, respectively over SSP as source of P. The physical mixture of MTRP + triple super phosphate (3:1) and 25% acidulated MTRP emerged as the best P sources with respect to grain yield and phosphorus use efficiency (Policegouder *et al.*, 1994).

Several workers have attempted to reduce the cost of P fertilisation in acid soils by combining a small proportion of water soluble P and large proportion of citrate soluble P in rockphosphate. Palophos (19.7% citrate soluble P_2O_5) was as effective as triple super phosphate in acid soil (Panda and Panda, 1969). In lateritic acid soils nitro-phosphate performed better compared to black soil (Dhua, 1971). The release pattern of P from insoluble phosphate sources in acid lowland rice soils of Kalyani showed that both basic slag and rock phosphate maintained a higher level of available P than superphosphate due to larger P-fixing capacity of those soils (Mandal and Khan, 1972). It was reported from acid laterite soils of West Bengal and weakly acid red loam soils of Orissa that citrate soluble source and powdered rock phosphate could efficiently be used if applied 15-20 days before puddling of rice fields (Patnaik *et al.*, 1971). Physical mixture of triple superphosphate and rock phosphate in varying proportion was as good as TSP for rice (Panda and Panda, 1969). Polymer coated P-fertilizers producing greater yields and fertilizer use efficiency than non-coated P-fertilizers in Alberta soils (near neutral Black chernozems of silty loam soils) was reported by Nyborg *et al.* (1995). Sawant and Kibe (1968) and Raut (1972) reported that coating of fertilizer resulted into slow release of available forms of phosphorus.

In rice-groundnut and rice-greengram cropping systems under rainfed conditions, application of acidulated rock phosphate or mixture of rock phosphate and superphosphate in 22:75 or 50:50 proportion has also been found to be a better source of P compared with superphosphate (Pillai *et al.*,1985). Application of phosphorus to rice through rockphosphates singly or in combination with lime proved beneficial for increasing yield of rice on an oxisol (acidic) (Prakash *et al.*, 1994).

Crop responses to P-application and level of phosphorus : Paddy soils are low to medium in available P and therefore, response of rice to P-fertilization is variable and location specific. Response to P application is highly erratic due to direct and indirect influences of several factors operating in the soil system on P availability to the plants. In general, the response of lowland rice is usually lower than for other dryland crops including upland rice, primarily because of increased solubility of native P in flooded soils. Rice generally responded upto 13 kg P_2O_5 ha^{-1} while wheat responded to more (26kg P ha^{-1}) based on single crop experiment in different locations of India (Abrol and Meelu, 1998). They observed that when 26kg P ha^{-1} was applied to wheat, rice did not respond to P. Efficiency of phosphate is improved if applied to wheat only in rice-wheat system. The residual effect goes to rice (Kanwar and Sekhon, 1998; Abrol and Meelu, 1998). Sharma (1995) also reported that rice did not respond to P and application of 40kg P_2O_5 ha^{-1} to wheat alone was sufficient to meet the P requirement of both crops at Ludhiana. Studies in China shows that, P uptake by crops and total yield of wheat and rice was doubled when all the fertilizer P applied to the upland wheat crop compared with all the P applied to rice (Run-Kun *et al.*, 1982). The different responses to P by the two crops in the rice-wheat system are ascribed to increased availability of soil P under submerged conditions (Gill and Meelu, 1983). Application of phosphorus along with N has been found essential particularly under the deficient soil and flash-flood conditions (Reddy *et al.*, 1991). Under intermediate deep water, there was no response to different levels of P in the first year but in the second year when the crop was grown in the same layout as of the previous year, a progressive increase in rice yield upto 60kg P_2O_5 ha^{-1} was reported (Sharma, 1995). In contrast, there was little further response in grain yield of different upland rice cultivars at higher rates than 60kg P ha^{-1}. The rice cultivars differed in agronomic and physiological P efficiencies and the effectiveness were higher at lower rates of P in ultisol (low in available P). The rooting depths of the cultivars were increased by application of P at the lowest application rate (30kg P ha^{-1}) (Sahrawat *et al.*, 1995).

Fertilizer P recommendations and P response is based on estimates of potential soil P supply (kg P ha^{-1} per crop) and crop P uptake (Janssen *et al.*, 1990). To predict the potential P supply in lowland rice soils, Olsen-P (Olsen *et al.*, 1954) or, to a lesser extent, Bray 1-P (Bray and Kurtz, 1945) are recommended as indices of available soil P in flooded rice soils (Chang, 1976). However, critical levels of Olsen-P reported for rice range from 4-29 mg P kg^{-1} (Goswami, 1986 and Panda *et al.*, 1981) and soil test values were frequently not correlated with yield response to P application in the field (Chang, 1976 and Nambiar *et al.*, 1973). Dobermann (1996) reported that for intensive irrigated rice systems in wide range of soil classes (Entisols, Inceptisols, Vertisols, Mollisols and highly weathered soils) uptake of 1.8-4.2 kg P was required to produce one ton of grain yield. They also observed that present recommendations for P fertilizer used on rice of 20-25 kg P ha^{-1} are adequate to maintain yields of 5-6 t ha^{-1}, but sustaining higher yields of 7-8 t ha^{-1} will require farm specific management strategies based on knowledge of the long- term P balance and soil P-supplying capacity.

In sodic soils (high pH and available P) of Indo-Gangatic Plains, Chhabra (1985) observed that neither rice nor wheat responded to P in the initial 3-5 years after reclamation. However, after 4-5 years, rice yields were reduced in the absence of applied P. In the same areas, Anand Swarup and Singh (1989) later reported that wheat responded to P after 11 years cropping when available P-status in the top 15 cm was reduced to 8.7 kg ha^{-1} and close to the critical level, 11.6 kg ha^{-1} in the deeper soil horizons.

Fageria and Filho (1991) reported that maximum yield was obtained at about 150kg P_2O_5 ha^{-1} in an oxisol of Brazil. In typic haplustalf (pH 8.1) soils, P applied at 100 per cent recommended dose (38 kg P_2O_5 ha^{-1}) recorded maximum grain and straw yield of rice (Annadurai and Palaniappan, 1994). The available P status of saline soils is highly variable and showed no regular trend in relation to soil salinity (Swarup, 1995).

In the districts of Palghat, Kottayam and Ernaculum of Kerela hardly any yield difference was obtained between Mussoorie rock phosphate and SSP at 32.5 kg ha^{-1}. No significant difference of rice yield was obtained between SSP and RP at 80 $kgha^{-1}$ in acid soils of Jorhat (pH 4.9). In the northern plateau region of Orissa mixed red and yellow acid soils were well managed with 40kg P_2O_5 ha^{-1} added through the combined source of RP and SSP. Rice-groundnut system did well with 60kg P_2O_5 ha^{-1} when RP and SSP were applied at 4:1 ratio (at soil pH 5.5). In the leached alluvial acid soils of coastal tract of Orissa, rice-wheat and rice-sesamum did well with 60kg P_2O_5 ha^{-1}. Rice-mustard-rice could be managed by 50kg P_2O_5 ha^{-1} applied in a combined form (Panda, 1998).

A rice variety with profuse rooting will have advantage for better uptake of applied phosphatic fertilizer (Mishra, 1991). Significant response to application of P in terraced upland rice was observed at Ranchi where, application of 40 kg ha^{-1} of P_2O_5 was the optimum dose for upland rice (Mahapatra and Srivastava, 1983). At Hazaribag (available P in soil was 30 ppm), the maximum grain yield and response to applied P was 15 kg P_2O_5 ha^{-1} (DRR, 1994 and 1995).

In Molisols of Uttar Pradesh, in long-term fertilizer experiment on rice-wheat system response of rice to P has appeared after eight years of continuous double cropping, whereas in wheat crop, there was response to P just after two rice-wheat cropping cycles (Modgal *et. al.*, 1995). In rice-cotton system in Tamil Nadu, phosphorus applied to rice could meet the need of cotton (Palaniappan and Annadurai, 1995).

Influence of method of phosphorus application on phosphate utilization : Phosphorus added to soil quickly become fixed in less available forms as the P reacts with other soil components. Application method can offset the effect of P-fixation by soils and increase P-efficiency. Fertilizer placement helps overcome fixation

(Anonymous, 1999). It was reported that dual banding N and P in the fall or spring prior to seeding has increased P-efficiency and yields (Anonymous, 1999). When placed together in a band the ammonium-N keeps fertilizer P-available longer by delaying the effects of normal soil reaction that fix P.

Ghosh *et al.* (1977) reported that for rice surface application or broadcast and mixing it by puddling was best as it resulted in greater P-availability. Application of P in the seed furrow just before seeding of rice was found to be better for upland rice than its broadcasting followed by incorporation into the soil (Mishra, 1999). Deep placement of water soluble N, P and K fertilizers can be agronomically more efficient as compared with their conventional methods of application in rice (IFDC, 1993; Kim and U.Z.K., 1977; Savanta *et al.*, 1993).

Rice seedlings root dipping in SSP slurry appeared much effective in increasing the grain yield and P-uptake by crop (Singh *et al.*, 1994) and to mitigate Fe-toxicity and P-deficiency in rice during *Kharif* season.

Influence of time of phosphorus application : Split application of phosphorus may be useful in cases where initial supply of the nutrient is sufficient to meet the early requirements of the crops. Regardless of the P-sources used, application of 60 kg P_2O_5 ha^{-1} in two equal splits, 50 per cent at transplanting and 50 per cent at tillering, was effective in increasing rice yields at Aduthurai [pH 6.8 and medium in available soil P] (Budhar *et al.*, 1992). Split application of phosphorus @ 60kg P_2O_5 ha^{-1} as diammonium phosphate resulted in higher P utilization (Goswami and Kamath, 1984). In soils that respond to P, fertilizer application should be made not later than the mid tiller growth stage or shortly after flooding for most efficient use of fertilizer P (Slaton *et al.*, 1998).

Pulses and oilseeds make better use of P applied directly because low temperature and unsaturated soil condition during *rabi* season hinder P diffusion and absorption by the roots (Dev and Sanders, 1988). On the other hand *Kharif* rice can make better use of residual P because of its increased availability due to higher temperature and submergence of the soil.

Annadurai and Palaniappan (1994) observed that application of P at recommended dose (38 kg ha^{-1}) basally and DAP spray (2%) thrice at boot leaf stage, 50 per cent flowering and post milk stages gave the highest yield of wet season *Kharif* rice.

Phosphorus management through integrated nutrient management : Integrated system approach is not only a reliable way of obtaining fairly high productivity with substantial fertilizer economy, but also a concept of ecological soundness leading to sustainable agriculture.

Application of composted as well as recycled poultry and pigeon manures as pond silt and mushroom spent substrates applied to rice @ 5 t ha^{-1} exerted greater influence on the productivity of rice-soybean-sunflower and rice-gingelly-maize cropping systems at Coimbatore (Chinnusamy *et al.*, 1997). In calcareous soil of Pusa (Bihar), application of 10 t ha^{-1} FYM + BGA substituted 25 per cent NPK in rice and residual equivalent to 25 per cent NPK in succeeding wheat in rice-wheat system as reported by Prasad (1994a) who also observed that the status of available P (15kg P_2O_5 ha^{-1}) was highest in the application of FYM + BGA. In another study, Prasad (1994b) reported that organic manures (Biogas slurry, Water hyacinth, Compost and FYM) can substitute 50 per cent phosphate (30kg P_2O_5 ha^{-1}) in rice production and there was residual effect equivalent to 30kg P_2O_5 ha^{-1} as chemical fertilizer on the yield of succeeding wheat crop in calcareous soils. Combined application of MRP, enriched farm yard manure (EFYM) and daincha had increased rice grain yield which was comparable to application of SSP alone was reported by Paulraj and Velayudham (1995a). Application of Mussoorie rock phosphate (MRP) with green manures was found to increase the available P to rice under low land condition (Ranjan and Kothandaraman, 1986). Roy *et al.* (1997) observed an increase of 24 per cent in grain yield of paddy over check plot (SSP @ 26 kg P ha^{-1}) with the combined effect of legume straw, MRP and phosphate solubilizing micro-organisms.

MRP-EFYM with parthenium applied to the preceding rice registered highest grain yield and haulm yield of blackgram in rice-blackgram system at Coimbatore (Paulraj and Velayudham, 1995b).

The residual effect of FYM in increasing yield of rice-pulse system has been reported by Meelu and Morris (1984); Lekha Sreekantan (1987) and Mashina *et al.* (1988).

Phosphate bio-fertilizer for rice and rice based cropping system : Use of biofertilizer or microbial inoculant to replace or increase the efficiency of chemical fertilizer partially or totally is effective in reducing the cost of crop production (Subba Rao, 1984) and maintaining ecological balance (Dey, 1990). Moreover it helps to maintain natural fertility of the soils. Bioinoculant *Bacillus firmus* (NCIM 2636) in combination with rockphosphate and organic manure serve as an excellent biofertilizer and is superior to SSP in acid soils (Datta *et al.*, 1992; Datta and Banik, 1997).

The phosphate solubilizing micro-organisms specially the phosphobacteria, have increased the activity in the neutral to slightly alkaline pH range (Wani and Patil, 1979) and produce various organic acids of their own in the rhizosphere (Pareek and Gaur, 1973). Roy *et al.* (1997) observed an increase of 27 per cent grain yield of rice with combined effect of legume straw, MRP and phosphate solubilizing microorganism over check plot (SSP @ 26.2 kg P ha^{-1}) at Varanasi (Udic Ustochrepts soils, pH 8.1).

Positive response to phosphobacteria inoculation in low land rice was reported by Anthoni Raj *et al.* (1994) at Aduthurai. In contrast, Paulraj and Velayudham (1995) reported that phosphobacteria inoculation didn't exert striking influence with MRP and subsequent P availability to rice.

Long term effect of P application (Balanced fertilization / P - balance sheet in soil) : In long term experiment for intensive irrigated rice system at different locations in Asia, Doberman *et al.* (1996) observed that physiological P use efficiency varied between 220 to 900 kg grain kg P ha^{-1}. Without added P there was a net loss of 7 to 8 kg P ha^{-1} per crop and with added P there was a net gain of 4 to 6 kg P ha^{-1} per crop. Average yield is increased from P application along with N and K in rice-rice cropping system. Jansen *et al.* (1996) also observed from the longterm experiment that, with a limited supply of soil P, the crop utilize the acquired P more efficiently in the formation of grain yield.

Evolution of balanced fertilization strategies for rice-wheat system with respect to P component has to consider that "there is little residual effect of P-applied to rice on succeeding wheat crop whereas rice benefits considerably from the application of P to the preceding wheat crop" (Dash *et al.*, 1981; Gill and Meelu, 1983; Saggar *et al.*, 1985). In north-western India, the yield of rice-wheat system could be maximised either by fertilization of both rice and wheat components or by applying P only to wheat @ 60 kg ha^{-1}. However the fertilization of each crop resulted in the build up of positive balance (Rattan and Singh, 1997).

Kolar and Grewal (1989) reported that direct application of 30kg P_2O_5 ha^{-1} to each crop in rice-wheat system resulted in significantly higher productivity compared to 60kg applied P_2O_5 ha^{-1} either to rice or wheat alone. Goswami and Singh (1976) propounding the concept of fertilising the wheat component of rice-wheat system could not draw any valid conclusions across the different soil groups. Dev (1992) demonstrated that for harnessing the highest yields of rice-wheat system, the rates of fertilizer application should be 120-30-30 with green manuring of rice and 180-30-30 without any green manuring of rice and 180-90-90 in wheat.

In a 12 years field experiment at Karimganj (acidic soils, pH 5.5, available P 65kg ha^{-1}), Kurmi *et al.* (1994) reported that P, K and their combination alone in rice-rice systems failed to enhance the grain yield consistantly throughout the experimental period, while combined application of N, P and K resulted in significantly higher yield.

In different rice based cropping systems in cauvery delta zone of Tamil Nadu, Chandrasekharan and Sankaran (1996) observed that when recommended balanced fertilizer were supplied to each crop in the system, computed balance for phosphorus was positive in all the systems and the highest was 196.3 kg ha^{-1} in system possessing rice-soybean. Wherever cotton constituted a component in the sequence (Finger millet-Rice-Cotton and Maize-Rice-Cotton), there was considerable enhancement of soil nutrient status. In rice-rice cropping system, any reduction in NPK fertilizer to 75 or 50 per cent of the recommended doses to each crop decreased the grain yield significantly (Rajkhowa and Baroova, 1991) which indicates application of recommended NPK fertilizers to both the crops is essential for getting sustained productivity.

Interaction of phosphorus and their management : The positive N x P interaction is of great significance. There are several reports that in highly P deficient soils, N can even be ineffective (Katyal, 1978; Mandal *et al*., 1971; Nambiar and Ghosh, 1984). Ryan and Sutton (1990) shows the positive N x P interaction by using nitrophosphate (contains 80 per cent water soluble P). The synergism between ammonium and phosphate in the same granule helps to increase phosphate uptake (and yield) particularly at the seedling stage of plants, when the root system is small and consequently phosphate uptake is limited (Cope *et al*., 1967; Crunes, 1959). However, the cuases of this positive N x P interaction are still not known. Various effect have been suggested (Engelstad and Allen, 1971), but most likely are a slowing a basic calcium phosphate formation in the soil, greater root proliferation at the site of localised high ammonium concentration and a root physiological effect of ammonium. Bao *et al*. (1996) also reported positive interaction of N and P and yield with N and P together were longer and more stable throughout the 15 year period of experiments. Bulbule *et al*. (1995) observed the positive N x P interaction in *Kharif* rice on farmers field at Maharashtra. Sengupta and Narula (1973) showed that ammonium nitrate gave higher responses and higher wheat yields than urea. Savant *et al*. (1993) reported that NP management can ensure positive interaction between the lower plant population (25 hills/m^2) and deep-placed N and P in lowland rice.

Deficiencies of P and K in rice have been appearing more frequently across the rice growing region of Arkansas and in these areas, P and K fertilization increase yields of rice, especially on soils with a pH greater than 7.0 (Wilson *et al*., 1995).

P x Zn interaction is important as deficiencies of both nutrients are widespread in Indian soils, particularly in intensively cropped areas. The antagonism between P and Zn is observed when both are deficient but only one of them, generally P has been applied. Through proper nutrient management, in which P and Zn levels match each-other, the antagonism can be neutralized and the same interaction can be converted into an additive effect (Prasad *et al*., 1983). Direct application of inorganic zinc sources to rice proved beneficial particularly in increasing the availability of phosphorus in rice-gram cropping system (Indulkar and Malewar, 1990). Positive relationship of P and Zn in soil was also reported by Chatterjee *et al*. (1983). Among the sources of zinc, zincated suphala (zinc blend with N and P contain complex fertilizer 20:20:0) was very promising in increasing the availability of P on succeeding crop in rice-gram systems (Indulkar and Malewar, 1990).

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