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Phosphorus Fertilization for Rice and Control of Environmental Pollution Problems

A.T.M.A. Choudhury, I.R. Kennedy, M.F. Ahmed and M.L. Kecskés
SUNFix Centre for Nitrogen Fixation, Faculty of Agriculture, Food and Natural Resources, Ross Street Building A03, The University of Sydney, NSW 2006, Australia

Abstract: Aim of this study to review information on various aspects of P fertilization in rice i.e., P nutrition of rice, P response of rice plant, P availability in rice soils and P adsorption in rice soils for better understanding of P fertilization in rice culture. A substantial portion of the applied P along with the soil P is lost from rice fields to water bodies causing environmental pollution problems through eutrophication. These pollution problems can be minimized by using proper source of P as fertilizer, proper timing and methods of P fertilizer application, soil P management, transport management, use of plant growth promoting microorganisms which helps in efficient use of P by crops and use of green manure crops which improves soil fertility as well as helps in efficient use of P by crops.

Key words: Phosphorus, fertilizer, rice, environment, soils, pollution

INTRODUCTION

Rice (*Oriza sativa*) crops require about 3-4 kg P for the production of one ton of rough rice including straw (De Datta, 1981; Ponnamperuma and Deturck, 1993; Sahrawat, 2000). This element is involved in the supply and transfer of energy for biochemical processes in the rice plant. Phosphorus deficiency exists in rice soils elsewhere in the world (Kawaguchi and Kyuma, 1977; Goswami and Banerjee, 1978). In addition, continuous rice cropping without P fertilization causes depletion of the soil P level even in the fertile soils in the long run (BRRI, 1996). So, fertilizer P application is essential to meet the crop demand as well as for the maintenance of soil P level. The amount of P fertilizer to be applied depends on soil P status, P adsorption in soils, environmental conditions and crop management practices (Abedin and Saleque, 1998; Kirk *et al*., 1998; Saleque *et al*., 1998). A substantial portion of the applied P fertilizer along with soil P is lost from the rice fields to water bodies resulting in environmental pollution problems through eutrophication (Sharpley *et al*., 2001). Over enrichment in nutrients is called as eutrophication. These issues should be kept in mind while applying P fertilizer in rice crop. This study reviews information on various aspects of P fertilization in rice.

PHOSPHORUS NUTRITION OF RICE

Phosphorus uptake varies among rice varieties (Table 1). This variation is dependent on soil fertility and rice variety (Choudhury *et al*., 1992; Choudhury, 2000). Phosphorus content of 0.10% in the leaf blade of rice plant at tillering stage is considered as the critical deficiency level (Yoshida *et al*., 1976). Phosphorus stimulates both root and shoot development and promotes flowering and grain development (De Datta, 1981).

PHOSPHORUS RESPONSE OF RICE PLANT

Rice plant responses to P fertilization in both upland and wetland conditions. Although P availability is higher in wetland soils due to the effects of flooding

Table 1: Phosphorus uptake by different rice varieties

Rice variety	Yield (t ha^{-1})		P content (%)		P uptake (kg ha^{-1})			Total P uptake (kg) for the production of one ton of rough rice	References
	Grain	Straw	Grain	Straw	Grain	Straw	Total		
MR84	7.7	7.6	0.24	0.10	18.48	7.60	26.08	3.39	Choudhury, 2000
BR1	4.3	4.0	0.24	0.05	10.32	2.00	12.32	2.87	Choudhury *et al.*, 1992
BR22	4.6	4.4	0.26	0.06	11.96	2.64	14.60	3.17	Choudhury *et al.*, 1992
BR3	5.7	5.4	0.26	0.07	14.82	3.78	18.60	3.26	Choudhury *et al.*, 1994
BR11	5.4	5.9	0.24	0.06	12.96	3.54	16.50	3.06	Choudhury *et al.*, 1994

Corresponding Author: A.T.M.A. Choudhury, SUNFix Centre for Nitrogen Fixation, Faculty of Agriculture, Food and Natural Resources, Ross Street Building A03, The University of Sydney, NSW 2006, Australia

Table 2: Effects of P fertilization on straw and grain yields of different rice varieties and agronomic efficiency of added fertilizer P

Rice variety	P fertilization	Straw yield (t ha^{-1})	Grain yield (t ha^{-1})	Agronomic efficiency*	Percentage increase in grain yield over control	References
BR29	Without P	3.04	1.67	-	-	BRRI, 1996
	With P (30 kg P ha^{-1})	4.45	4.45	92.67	166.47	
BR11	Without P	4.07	2.51	-	-	
	With P (30 kg P ha^{-1})	4.84	4.00	49.67	59.36	
BR32	Without P	6.17	4.34	-	-	BRRI, 1997
	With P (50 kg P ha^{-1})	6.29	4.76	8.40	9.68	
IR66	Without P	1.78	0.77	-	-	Pheav *et al.*, 2003
	With P (16.5 kg P ha^{-1})	3.89	2.08	79.39	170.13	

*Agronomic efficiency (kg grain kg^{-1} added P) is calculated from the difference in grain yield in kg between control and P fertilized treatments divided by the P fertilizer rate used in kg

(Ponnamnperuma, 1972; Choudhury, 1986), there are deficiencies of P in Ultisols, Oxisols, Vertisols, Inceptisols andisols and acid sulfate soils (Diamond, 1985). Table 2 indicates the P response of different rice varieties. Rice yield varies considerably due to the P status of rice soils. In a field trial at Bangladesh Rice Research Institute, the effects soil P level on P nutrition and yield of rice were evaluated using five modern rice varieties under wetland conditions (Saleque *et al.*, 1998). It was observed that rice yield increased linearly with an increase in soil P content up to 6 mg kg^{-1}. Phosphorus response behavior varies among the rice varieties. Experimental results at EMBRAPA, Brazil showed that there were marked differences in P response among the 12 rice genotypes tested (Fageria and Santos, 2002). Phosphorus response of rice plant can be enhanced by elevating carbon dioxide level (Seneweera *et al.*, 1994). Rice varietal traits like root-exuded acid phosphatase, root-exuded proton, root dry weight and P uptake rate contribute to increasing P mobilization capacity of the rice plant in P deficient soils (Ming *et al.*, 2002). Field experimental results indicated that P fertilization in upland rice could significantly increase the productivity of the Ultisols (Sahrawat *et al.*, 1995, 1999). In general, the most responsive soils are black, red, yellow and coastal alluvial soils (Goswami, 1975).

PHOSPHORUS AVAILABILITY IN RICE SOILS

Phosphorus availability in wetland rice soils is higher than upland soils. The pH values of acid soils increase due to flooding largely because of the reduction of Fe; but the stable pH of the submerged soils is regulated by the partial pressure of CO_2 (Ponnamnperuma, 1972). The pH values of alkaline soils decrease due to flooding because of accumulation of CO_2. Ferric and Al compounds of P release P as pH increases while Ca compounds of P liberate P as pH decreases. Generally, after flooding, concentration of water-soluble P increases (De Datta *et al.*, 1990). The availability of native and added P is higher in flooded soils than in well-drained soils (Ponnamperuma, 1965; Patrick and Mahapatra, 1968). Phosphorus availability is higher in higher temperature (Saleque *et al.*, 1996).

PHOSPHORUS ADSORPTION IN SOILS

When P fertilizer is added to the soils, a substantial portion of it is fixed in the soil. Phosphorus fixation in soil involves both adsorption and precipitation reactions, although adsorption is dominant over a short period (Rajan and Watkinson, 1976; Mehadi and Taylor, 1988). The P adsorption data can be fitted into the Langmuir, Freundlich and Temkin adsorption equations (Sanyal *et al.*, 1993). Maximum P adsorption capacity and the constant of energy of P adsorption can be calculated from the Langmuir equation while the P buffering capacity (retention capacity of the adsorbed P) can be calculated from the Temkin equation (Abedin and Saleque, 1998). Experimental findings showed that maximum adsorption capacity, buffering capacity and the constant of energy of adsorption varied among soils (Abedin and Saleque, 1998). Phosphorus adsorption is generally higher in the flooded rice topsoils than in the upland topsoils (Kuo and Mikkelsen, 1979). High phosphorus adsorption in the flooded rice topsoils is attributed to the higher content of amorphous iron resulting from reduction caused by seasonal soil submergence (Kuo and Mikkelsen, 1979). The increase in P adsorption due to flooding is higher at higher temperature (Quang and Dufey, 1995). Phosphorus adsorption is higher in soils with higher Cation Exchange Capacity (CEC) and vermiculite content (Sardi and Csatho, 2002). Phosphate adsorption can be reduced by 40% by adding strongly chelating ligands (e.g., malate) in the soils (Antonio *et al.*, 2002). This practice can increase the mobility of P for plant uptake. However, excess mobilization of P may cause P losses resulting environmental pollution problems.

PHOSPHORUS LOSS FROM RICE SOILS AND ENVIRONMENTAL POLLUTION PROBLEMS

The applied P is lost from the rice fields by both runoff and leaching mechanisms (Kyuma, 1990; Heckrath *et al.*, 1995). The estimated runoff of P from rice fields was found as 4.5 kg ha^{-1} year^{-1} in Korea (Cho, 2003). The runoff loss originates primarily from small areas within watersheds during a few storms (Sharpley *et al.*, 2001). Phosphorus losses also occur from soil erosion processes (Ward *et al*., 1990). The lost P goes to water bodies accelerating freshwater eutrophication (Carpenter *et al*., 1998, 1999). Eutrophication restricts water use for fisheries, recreation and industry due to the increased growth of undesirable aquatic weeds and algae, and oxygen shortages resulting from their death and decomposition (Sharpley *et al*., 2001; Carpenter *et al*., 1998). Eutrophication has many other negative effects on aquatic ecosystems like increased biomass of phytoplankton, shifts in phytoplankton to bloom forming species that may be toxic or inedible, increases in blooms of gelatinous zooplankton, increased biomass of benthic and epiphytic algae, and changes in macrophyte species composition and biomass (Carpenter *et al*., 1998). In many cases, surface waters have experienced harmful algal blooms, which contribute to summer fish kills, unpalatability of drinking water, formation of carcinogens during water chlorination and links neurological impairment in humans (Sharpley *et al*., 2001; Kotak *et al*., 1993). Loading of P in lakes supports the growth of blue-green algae, which are usually P limited and can form noxious blooms (Soranno *et al*., 1996). Therefore, P losses in soil-water system should be minimized by efficient management practices for the protection of environment.

PHOSPHORUS FERTILIZER MANAGEMENT FOR RICE PRODUCTION

The environmental pollution problems due to P fertilizer losses are of a great concern to the administrators, policy makers, agronomists, soil and environmental scientists around the world. Appropriate management strategies to minimize P fertilizer losses and to reduce the application of chemical P fertilizer should be taken. These include P source, timing and methods of P fertilizer application, soil P management, transport management, use of plant growth promoting microorganisms, which enhance plants capacity to utilize P efficiently and use of green manuring crops.

Phosphorus sources: The most commonly used P fertilizers for lowland rice are single and triple superphosphates, diammonium phosphate and ammonium phosphate (Sanyal and De Datta, 1991). There is no evidence of differences in rice responses to various sources of water-soluble P (Diamond, 1985). Triple superphosphate is generally used for rice cultivation in Bangladesh, Pakistan and India (De Datta, 1981; BRRI, 1996). Phosphate Rocks (PR) are also used as P fertilizers in many countries including Malaysia, Sri Lanka and Thailand (De Datta, 1981). The application of PR to lowland rice meets with two difficulties: (1) pH of an acidic soil will rise following submergence and this may adversely affects the solubility of PR in soil; (2) the ability of rice to derive P from PR is relatively low (Sanyal and De Datta, 1991). Several modifications of phosphate rocks have been suggested to increase its effectiveness (De Datta, 1981). Small phosphate rock particles (60-140 mesh) called mini granules, can be applied without the dust problem (De Datta, 1981). When water-soluble P fertilizers are added to rice crops in acid soils, these are fixed with Fe and Al becoming unavailable for plant uptake. On the other hand, when rock phosphate is used in acid soils, there is no chance of P fixation and P is released slowly and steadily throughout the growing period (Chakraborty *et al*., 2002). This applied rock phosphate develops a reserve of P in the soil, which results in higher availability of P for the succeeding crops. In India, better efficiency of rock phosphate was found in rice and rice based cropping systems in acid soils (Chakraborty *et al*., 2002). Other possible sources of P are iron-aluminum phosphate and magnesium phosphate (De Datta, 1978). The source of P to be applied in rice crops should be selected based on local availability, soil condition and price of the fertilizer material.

Methods of P fertilizer application: It has been established by ^{32}P-labeled fertilizer application that surface broadcasting or incorporation of fertilizer before transplanting is more effective than other methods such as deep placement of P at 10 or 20 cm depth either in planting hills or between rows (Sanyal and De Datta, 1991). Dipping rice seedlings into P fertilizer slurry before transplanting has also been reported to be useful (De Datta, 1981). This practice provided greater yield response than soil applications of similar rates of P on a P-deficient Vertisol in India (Katyal, 1978). In China, this practice resulted in a 40-60% saving on P fertilizer in irrigated rice soils (Diamond, 1985). Phosphorus fertilizer is also applied by drilling bands at seeding where rice is drilled in dry soil (De Datta, 1981). The method of P fertilizer application should be selected based on soil and crop conditions so that the applied P is used efficiently.

Timing of P fertilizer application: Phosphorus fertilizer is generally applied to rice at planting, but later application can be made provided it is not later than the time of active tillering (De Datta, 1981). Early application of P is essential for root elongation. Phosphorus applied during the tillering stage is most efficiently utilized for grain production. Split application of P is not beneficial because the mobility of P from old leaves to young ones is high and because the availability of soil P increases with time during submergence (De Datta, 1978). In India, it was found that rice yield decreased when P was applied at 7 Days After Transplanting (DAT) instead of at planting in the dry season while in the wet season the yield was not significantly affected even P application at 21 DAT (Katyal, 1978). Generally P is applied before planting at final land preparation in the transplanted rice (Choudhury *et al*., 1992, 1997) while it is applied at 15-20 Days After Sowing (DAS) in the direct seeded rice (Choudhury and Khanif, 2002). Field experimental results at alkaline soils of Arkansas, USA showed that P fertilizer application in three timings (before seedling emergence, at the 4-5-leaf stage and at 5-10 day post-flood) were equally effective in increasing rice grain yield while the application of P at the mid season (when the main stems topmost internode had elongated 0.5-1.5 cm) did not increase grain yield significantly (Slaton *et al*., 2002). The timing of P fertilizer application should be selected based on soil, crop and environmental conditions so that the applied P is used efficiently.

Soil P management: Soil is the natural source of P for all crops. Phosphorus deficiency in soils may develop in intensive cropping without the required amount of P fertilizer application resulting in decrease in yield of crops like rice, wheat and barley (Withers *et al*., 1994; BRRI, 1999). But excess amount of P application may cause P losses into water causing environmental pollution problems (Morgan, 1997). So judicious application of P fertilizer is needed to avoid P losses into water. There are three broad P fertilizer application strategies: (I) no P fertilizer is required for optimum production for a number of years when the soil P level is high, (ii) a maintenance rate of P fertilization is required when the soil P level is moderate, (iii) build-up of P is necessary when the soil P level is low (Tunney *et al*., 1997). Drying and rewetting increases mineralization of soil organic P especially when liming is done (Chepkwony *et al*., 2001). This practice can reduce the amount P fertilizer application by exploiting soil P for plant uptake. Incorporation of organic materials into the soil increases the availability of native P (Sauchelli, 1965). The amount of P fertilizer to be applied in crops should be fixed based on soil tests and environmental considerations rather than agronomic benefits only (Sharpley and Rekolainen, 1997).

Transport management: Phosphorus is transported from soil to water mainly through runoff and erosion (Kyuma, 1990; Ward *et al*., 1990). The transportation of P occurs both in dissolved and particulate forms (Sharpley *et al*., 1993; Sharpley and Withers, 1994). The dissolved P is mainly orthophosphate released from soil, vegetation and applied fertilizer. It is available for uptake by the aquatic biota (Peters, 1981). The particulate P is comprised of adsorbed P in the soil, mineral P and organic matter eroded during runoff, which can provide a long-term source of P to the aquatic biota (Sharpley *et al*., 1992). The amount of P transported to watersheds varies from 0.18-8.9 kg P ha^{-1} $year^{-1}$ (Harper and Stewart, 1987). The erosion and runoff losses can be reduced by increasing vegetative cover through conservation tillage (Sharpley and Smith, 1994). Other measures to minimize P loss through erosion and runoff include buffer strips, riparian zones, terracing, contour tillage, minimum tillage leaving straw on the soil surface, cover crops and impoundments or small reservoirs (Sharpley and Rekolainen, 1997; Chambers *et al*., 2000; Reed and Carpenter, 2002). Appropriate transport management strategies should be undertaken based on soil and environmental conditions.

Use of plant growth promoting microorganisms: Microorganisms can solubilize and mineralize P from inorganic and organic pools of total soil P (Richardson, 2001). These processes increase the availability of soil P for plant uptake and reduce the dependence on fertilizer P, which is lost into water causing environmental pollution problems. Many soil bacteria and fungi are able to solubilize various forms of precipitated P (Kucey *et al*., 1989; Rodriguez and Fraga, 1999; Whitelaw, 2000). The ability of the microbes to solubilize Ca-P complexes has been attributed to their ability to reduce the pH of their surroundings, either by release of organic acids or protons (Gyaneshwar *et al*., 2002). The commonly reported organic acids produced by microbes are gluconic, oxalic and citric acids (Illmer *et al*., 1995; Whitelaw, 2000). The P-solubilizing microorganisms may constitute up to 40% of the culturable population of soil microorganisms and a significant proportion of them can be isolated from rhizosphere soil (Kucey, 1983). Soil Microorganisms also play an important role in the mineralization of soil P (Richardson, 1994, 2001). Studies conducted at the International Rice Research Institute demonstrated that the uptake of P by the rice plant increased by 10-28% due to inoculation of rice plant with different rhizobial diazotrophs isolated from a wide range of legume hosts resulting in increase in growth and yield of rice (Biswas *et al*., 2000a , b). This practice enables rice plants to utilize P more efficiently and thus can reduce P loss, that causes environmental pollution. The acquisition of soil P by plants can also be enhanced by inoculation of mycorrhizal fungi (Marschner and Dell, 1994; Joner and Jakobsen, 1995). Plant growth promoting microorganisms should be used for the efficient use of P by crop plants.

Use of green manuring crops: Green manuring crops are used to improve soil fertility and to increase nutrient supply to the crops (Choudhury *et al*., 1996, 2002). The use of green manures can increase soils capacity to absorb nutrients and improve soil structure and microbial activities (Zaman *et al*., 1994, 1997). *Sesbania* is a widely used green manuring crop in rice growing countries, which can accumulate 1 kg P per ton of its dry matter (Bhuiyan and Zaman, 1996). Due to its extensive and deep root systems, it can accumulate P from deep soil layers, use insoluble or fixed forms of P and make them available for the succeeding rice crop (Ladha and Kundu, 1997). Another legume pigeon pea (*Cajanus cajan*) has also the ability to tap subsoil P and utilize insoluble P through its well-developed root system and when used as green manure, make P available to the succeeding rice crop (Ahlawat and Saraf, 1982). Use of green manures may increase the availability of P by decreasing the sorption of added P to soils (Ohno and Crannell, 1996). There is a good prospect of using green manuring crops for efficient use of P by rice plants.

CONCLUSIONS

A better understanding on P nutrition of rice, P response of rice plant, P availability in rice soils and P adsorption in rice soils is necessary before going for P fertilization in rice culture. Phosphorus is lost from both soil and fertilizer causing environmental pollution problems. These pollution problems can be minimized by better management practices those help in reducing P losses as well as in efficient use of P by rice crops. These include: (I) use of proper source of P as fertilizer based on soil, crop and environmental conditions, (ii) proper timing and methods of P fertilizer application based on soil, crop and environmental conditions, (iii) soil P management, (iv) transport management, (v) use of plant growth promoting microorganisms which helps in efficient use of P by crops and (vi) use of green manure crops which improves soil fertility as well helps in efficient use of P by crops.

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