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Research Communication

Phosphorus pools under integrated phosphorus management of upland direct-seeded rice (*Oryza sativa*) in North-Eastern Hill region of India

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ABSTRACT

A field experiment was carried out during the rainy (*kharif*) season of 2019 at Umiam, Meghalaya, to determine the phosphorus pools in acid soils of upland direct-seeded rice (*Oryza sativa* L.) in North-Eastern Hills region under varying phosphorus-management practices. Eight treatments with combinations of different nutrient sources, both organic and inorganic were taken replicated thrice in a randomized block design. The treatments involving chemical fertilizers resulted in higher levels of inorganic P (232 mg/kg) owing to an increase in Fe–P, Al–P and Ca–P pools. On the other hand, treatments utilizing organic sources of nutrients like farmyard manure (FYM), vermicompost and poultry manure showed higher levels of organic-P (168 mg/kg) in soil. Application of integrated organic nutrient sources as in 25% farmyard manure + 25% vermicompost + 25% poultry manure + phosphorus-solubilizing bacteria resulted in significantly higher available-P (5.5 mg/kg) and organic-P pool (168.2 mg/kg) over the other treatments. But the total P was significantly higher with 100% recommended fertilizer dose (391.5 mg/kg) which showed an increase of 10% over the control.

Key words : Direct-seeded rice, Phosphorus fractionation, Phosphorus solubilizing bacteria, Reductant soluble P, Soluble and loosely bound P

Rice is the staple food for more than half of the world's population. Rice accounts for 35–75% of the calorie intake by more than 3 billion people in Asia (Khush, 2010). The North-Eastern India is considered to be one of the gem baskets of rice genetic resources in the world. It is a potential rice-growing region, with extremely diverse rice-growing conditions as compared to other parts of the country. North-east India is characterized by high soil acidity, Al^{+3} toxicity, heavy soils, carbon loss, uneven water distribution leading to scarcity during most parts of year even though it is known as high-rainfall area.

Thus, addition of organic matter is considered as the noble intervention to improve the physical, chemical and microbiological properties of the soil. Falleiro *et al.* (2013) commented on the impact of organic nutrient sources on improvement of soil chemical properties like cation-exchange capacity and moderation of soil *p*H. The range of phosphorus-use efficiency values for crops lie between 10 and 30% in the year of application (Malhi *et al.*, 2002), which is very less compared to use efficiencies of N and K. Myint *et al.* (2010) stated the twin benefits of increasing soil fertility and cost reduction by application of organic manures. Prominent use of phosphorus-solubilizing bacteria (PSB) and plant growth-promoting rhizobacteria (PGPR) has the potential to reduce levels of phosphorus fertilizer application by almost 50% without causing any considerable reduction in crop yield (Jilani *et al.*, 2007). Availability of soil P for crops is strongly influenced by soil biota (Richardson and Simpson, 2011), its subsequent hydrolysis by microbes and plant-derived phosphatases which can further increase the P availability for plants. Thus, the organisms which enhance the uptake of P such as recommended dose of phosphorus (RDP); farmyard manure (FYM); vermicompost (VC); poultry manure (PM); phosphate-solubilizing bacteria (PSB); arbuscular mycorrhizal fungi (AMF), phosphorus solubilizing bacteria (PSB) and vesicular arbuscular mycorrhiza (VAM) are very important to improve P-use efficiency. Suir *et al.* (2013) reported direct correlation between VAM and PSB inoculation and grain protein content. Since most of the P gets fixed with Fe and Al oxides in acidic soil and with Ca in

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calcareous soil, the amount of plant available P could be meagre despite the high amount of total P in the soil. In this regard, population of microbes like that of PSB and enzymatic activities help to set optimum yields in a crop. The prominent reason for poor P concentration in soil lies in the ability of P to get fixed and precipitated in a wide range of *p*H values which affects nutrient uptake and causes reduction in yield levels (Zaidi *et al.,* 2009) Ligand-exchange reactions are mostly responsible for nutrient release from chelated metal ions and subsequent plant uptake. Phosphorus solubilizing bacteria releases fixed P by various mechanisms, such as the production of organic acids, chelation and exchange reactions, which lead to higher crop yields. The release of organic acids such as oxalic acid, malic acid, succinic acid and propionic acid by PSB like *Bacillus* sp. and *Pseudomonas* sp. Phosphate-solubilizing microorganisms have established their role for optimum growth of plants under nutrient imbalance conditions (Panwar, 2014). North-eastern states have nearly 6.7% cattle, 1% sheep, 5% goat, 40% pigs and 5% livestock population compared to their population at national level. This gives us enough scope to use their by-products such as manure as an organic source of nutrient in rice cultivation. Hence, there is a need to compare the effect of different organic and inorganic combinations of nutrient sources in direct-seeded rice and their role in enhancing different phosphorus pools in soil. Keeping this in view, an experiment was conducted to determine the amounts of phosphorus present in different pools in soil.

The experiment was conducted at Research Farm of the ICAR Research Complex for the North-Eastern Hill Region, Umiam (25°38' N, 91°53' E, 950 m above mean sea level), Meghalaya, during the rainy (*kharif*) season of 2019. The soil was sandy-clay loam, with *p*H 4.2; high in organic carbon (1.62%) and available K (354 kg/ha), medium in available N (256 kg/ha) and low in available P (6.3 kg/ha). Eight treatments were arranged in randomized block design with 3 replications, *viz.* control plot with no P; 100% recommended dose of phosphorus (RDP), i.e. 60 kg P_2O_5/ha; 50% RDP + 50% through farmyard manure (FYM); 50% RDP + 50% through vermicompost (VC); 50% RDP + 50% through poultry manure (PM); 50% RDP + phosphate-solubilizing bacteria (PSB) + arbuscular mycorrhiza fungi (AMF); 75% RDP + PSB + AMF; 25% through FYM + 25% through VC + 25% through PM + PSB. Rice variety 'Bhalum 3' was directly sown using a seed rate of 25 kg/ha at 20-cm-row spacing. The crop was fertilized with recommended dose of 80 : 60 : 40 kg N, P_2O_5 and K_2O/ha. The phosphorus-fractionation scheme was followed to determine the amounts of phosphorus present in different pools in soil. The phosphorus-fractionation technique was used to determine phosphorus pools in soil which helped in separation of Fe–P, Al–P and Ca–P fractions in soil. Total organic phosphorus was determined by the ignition method. The organic phosphorus was converted to inorganic phosphorus by ignition method due to high temperature. The organic phosphorus was determined by the difference between amount of sulphuric acid (H_2SO_4)-extractable inorganic phosphorus for ignited and unignited soils. Organic phosphorus was the difference between total ignited phosphorus and total unignited phosphorus. Fractionation of inorganic P method utilizes the chelating capacity of fluoride ion (F^-) from ammonium fluoride (NH_4F) to separate Al–P from Fe–P. It is then followed by removal of Fe–P with sodium hydroxide (NaOH) and reductant soluble P with sodium citrate ($Na_3C_6H_5O_7.2H_2O$)–sodium dithionate ($Na_2S_2O_4$)–sodium bicarbonate sulphuric acid (H_2SO_4) or hydrochloric acid (HCl). The soil samples from the 8 treatments were subjected to phosphorus-fractionation technique. Data were

Table 1. Effect of nutrient-management practices on different pools of phosphorus in soil

Treatment	Soluble P (mg/kg)	Al–P (mg/kg)	Fe–P (mg/kg)	Ca–P (mg/kg)	Reductant soluble P (mg/kg)	Inorganic P (mg/kg)	Organic P (mg/kg)	Total P (mg/kg)	Yield (t/ha)
Control	2.31	72.3	21.7	52.3	52.5	201	153	354	3.77
100% RDP	4.42	80.7	32.4	55.9	58.8	232	159	392	4.57
50% RDP + 50% FYM	3.79	77.4	25.7	54.5	55.6	217	161	377	4.49
50% RDP + 50% VC	3.98	78.1	26.4	55.1	56.3	220	161	381	4.50
50% RDP + 50% PM	4.20	78.6	27.2	55.6	57.4	223	162	385	4.52
50% RDP + PSB + AMF	3.41	74.2	23.1	52.3	53.1	206	162	369	4.46
75% RDP + PSB + AMF	4.63	75.1	25.3	52.8	54.5	212	164	376	4.53
25% FYM + 25% VC + 25% PM + PSB	5.53	76.6	27.8	54.3	55.1	219	168	388	4.97
SEm±	0.30	0.60	0.40	0.02	0.04	0.22	1.06	1.07	0.11
CD (P=0.05)	0.91	1.80	1.22	0.06	0.13	0.65	3.18	3.22	0.32

RDP, Recommended dose of phosphorus; FYM, farmyard manure; VC, vermicompost; PM, poultry manure; PSB, phosphate-solubilizing bacteria; AMF, arbuscular mycorrhizal fungi analysed using analysis of variance (ANOVA). Treatment means were separated using the least significant difference (LSD) at 5% level of significance and differences more than LSD were considered significant.

The different forms of phosphorus pools in soil are soluble and loosely bound P, Al–P, Fe–P, Ca–P, reductant soluble P, inorganic P, organic P and total P. The phosphorus pools in soil were determined after harvesting of the crop. Inorganic P is the sum total of soluble and loosely bound P, Al–P, Fe–P, Ca–P and reductant soluble P. Organic forms of P include inositol hexaphosphates, phytin and nucleic acids. Among all these forms, inositol hexaphosphate remains the dominant form which often gets transformed to inorganic soluble forms by phosphatase enzymatic activity. Total P is the sum total of inorganic-P and organic-P. The only form of phosphorus which is available is soluble and loosely bound form which is taken up by the plants through phosphate ions. Other forms get fixed in the soil, thus making P unavailable for crop growth. The P is bound as Fe–P and Al–P in acid soils and as Ca–P in calcareous and alkaline soils. The soils of North-Eastern Hill region are very acidic having a *p*H of 4.2 thus making more amounts of phosphorus to be bound to Al and Fe oxides. Among Fe and Al bound P, Al–P is the dominant one owing to the highly acidic condition of soil with a *p*H of 4.2.

The different pools of P available in soil are enumerated in Table 1. The soluble and loosely bound P which is the only form taken up by the plants in form of phosphate ions was found to be the highest in 25% FYM + 25% VC + 25% PM + PSB (5.5 mg/kg). It was followed by 75% RDP + PSB + AMF (4.6 mg/kg) and 100% RDP (4.4 mg/kg). All the treatments showed significantly higher values over the control (2.3 mg/kg). This form of P was directly related to grain yield of rice. The organically managed plot which gave the highest soluble P subsequently led to the highest grain yield (4.97 t/ha) among all treatments. It was followed by 100% RDP (4.57 t/ha) and 75% RDP + PSB + AMF (4.53 t/ha). Among all the fractions contributing to inorganic P, Al–P contributed the highest owing to its dominance in acidic soils at *p*H 4.2. The highest fraction of Al–P was found in inorganic plot consisting of 100% RDP (80.7 mg/kg), followed by 50% RDP + 50% PM (78.6 mg/kg) and 50% RDP + 50% VC (78.1 mg/kg). The Fe–P was the highest for 100% RDP (32.4 mg/kg) which was significantly higher over all other treatments. This was followed by 25% FYM + 25% VC + 25% PM + PSB (27.8 mg/kg) and 50% RDP + 50% PM (27.2 mg/kg). The Ca–P fraction was again the highest in 100% RDP (55.9 mg/kg) owing to the presence of 21% Ca through single superphosphate (SSP). It was followed by 50% RDP + 50% PM (55.6 mg/kg) and 50% RDP + 50% VC (55.1 mg/kg). Reductant soluble P was also the highest for 100% RDP (58.8 mg/kg). Rest treatments followed the same trend as that of Ca-P. In contrast to the inorganic P fractions, organic P fraction was found to be the highest in 25% FYM + 25% VC + 25% PM + PSB (168.2 mg/kg) which was significantly higher over rest of the treatments. Biofertilizers PSB and AMF had a significant impact on increasing the organic P fraction. The second highest organic-P pool was observed in 75% RDP + PSB + AMF (164.1 mg/kg), followed by 50% RDP + PSB + AMF (162.4 mg/kg). Organic manures in the form of vermicompost and poultry manure have significant amounts of Ca and Mg which help to neutralize soil acidity and release P in soil solution thus enhancing phosphorus availability to plant.

Thus, it can be concluded that application of organic manures in the proportion of 25% FYM + 25% VC + 25% PM + PSB resulted in the maximum value of available P in the form of soluble and loosely bound P which subsequently resulted in the highest grain yield. This P can be easily taken up by the plants through inorganic phosphate ions and would enhance crop growth and productivity to a great extent.

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