4R Phosphorus Management in Acid Soils of Odisha

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Phosphorus nutrition for crops grown in Odisha is challenged by widespread soil acidity.
Applying 4R principles of P management offers opportunities for improved crop yields while alleviating the problems associated with low soil pH.

Soil acidity and poverty are synonymous in the state of Odisha where 80% of soils are acidic. Low water holding capacity, high bulk density, and soil crusting along with chemical constraints like low pH, low CEC, low base saturation (16 to 67%), high Al, Fe and Mn saturation, and high P-fixing capacity (80 to 91%) are major reasons for low crop productivity in such soils (Misra et al., 1989).

Phosphorus is one of the most limiting nutrient in the soils of Odisha owing to P fixation and immobile nature of P (Pattanayak et al., 2008). Acid soils fix two-to-three times more P per unit surface area than neutral or calcareous soil and the fixed P in acid soil is held with five times more bonding energy than calcareous soils. The extent of P fixation from the added P varies from 97% under air-dry condition to 76% under submerged condition, which is dependent on the type and quantity of clay minerals, sesquioxide and organic matter content (Pattanayak and Misra, 1989). Even though the soils of Odisha are low (27%) to high (73%) in soil available P, crops grown in Odisha exhibited a significant yield loss due to omission of P, which is 37% in hybrid rice (Pattanayak et al., 2008) and 49% in hybrid maize (Pattanayak et al., 2009). Thus, a proper P management strategy is required for improving and sustaining crop yields in the acid soils of Odisha.

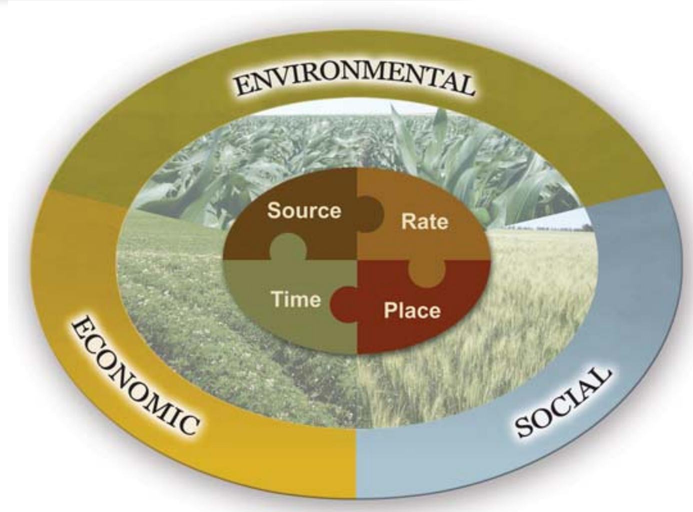
The right source of P application in acid soils depends on the nature of growing environment. Under submerged soil conditions, owing to relatively less P fixation and high solubility of native P, application of readily available water-soluble sources of P fertilizers are more appropriate. Such water-soluble sources are, however, less efficient for upland red and lateritic soils due to high P fixation.

Pattanayak et al. (2011) reported that the unproductive/less productive acid upland soils (Alfisols, Inceptisols, and Entisols) can improve crop yields through application of the right nutrient rates based on soil testing, integrated with organic and inorganic soil ameliorants. P fertilizer applied at right time showed higher crop yields while improving the efficiency of applied P in the acidic soils of Odisha (Misra and Pattanayak, 1997). Similarly, Arnall (2014) reported that in acid soils with low pH conditions, right placement of P fertilizers through banding helps to alleviate the impact of Al toxicity as phosphate reacts with metals like Al and Mn to form insoluble compounds and reduces the harmful effects of the metals on the emerging seedling. Recognizing the benefits of 4R principles of P management, this paper discusses the importance of 4R strategies of P management in acid soils of Odisha.

Right Source of P Application

The efficiency of a P source varies depending upon the proportion of water-soluble P and soil properties (soil pH, P-fixing capacity, and organic matter content). In neutral to alkaline soils, materials containing water soluble P are generally more efficient than materials containing citric acid soluble or citric acid insoluble P. However, in very acidic soils, rock phosphate is as effective as water-soluble P sources for crops like rice (Singh and Singh, 2001). While managing acid soils, some forms of rock phosphate (RP) are known to be an appropriate economic source of P. However, RP sources available in India (Mussouriee RP, Udaipur RP, and Purulia RP) are relatively low grade and less reactive (Biswas et al., 2009) in nature. Use of such RP sources may result in low crop yields due to mismatch between crop uptake and P supply.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Al = aluminum; B = boron; Cu = copper; Fe = iron; Mn = manganese; CEC = cation exchange capacity; FYM = farmyard manure.



4R Nutrient Stewardship defines the right source, rate, time and place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem.

Mitra and Misra (1991) conducted a study in the red soils (Alfisol) of Semiliguda in Koraput district of Odisha where rice was grown in a soil with acidic pH (5.1 to 5.2) and low available P (Bray-1 P, 3 to 5 kg/ha). Four straight P sources were compared with two mixed sources of P at an application rate of 40 kg P/ha, and a common dose of N and K were applied to each treatment including control with P omission (**Table 1**). Results

Table 1. Evaluation of P sources in rice grown in red soils of Koraput.

P source*	Grain yield, t/ha	Relative Agronomic Efficiency, %
Control (No-P)	2.4	-
SSP	3.0	100
MRP	2.8	58
MRP+SSP (3:1)	2.9	80
MRP+SSP (1:1)	3.1	113
Complex (20:20:0:13)	3.1	115
DAP	3.1	110
LSD (p = 0.05)	0.2	-

Source: Mitra and Misra (1991).
*SSP = single superphosphate, MRP = Mussouriee rock phosphate, DAP = diammonium phosphate.

Table 2. Evaluation of P application rates for hybrid rice grown in soils with acidic pH.

Treatment	Yield, t/ha	Nutrient uptake, kg/ha N	P	K	Recovery efficiency, % N	P	K	Net benefit, Rs./ha
Control	4.9	83	15	148	-	-	-	11,252
ASI* - P	8.7	191	20.7	248	37	-	67	21,257
ASI + 25% P	9.7	207	28.2	293	43	70	97	27,142
ASI + 50% P	11.7	212	33.8	307	45	50	106	45,272
ASI + 75% P	12.9	224	36.7	346	48	39	132	54,957
ASI + 100% P	13.9	236	40	359	53	38	141	62,497
150% NPK	9.0	224	37	355	32	22	92	19,552
C.D. (p = 0.05)	0.47	3.5	1.8	20	-	-	-	

Source: Pattanayak et al., 2008
*ASI = Agro Services International analytical method (Portch and Hunter, 2002).
*Costs considered for calculation of economics are from 2008: hybrid rice = 8.5 Rs./kg, N = 11 Rs./kg, P_2O_5 = 22 Rs./kg, K_2O = 8 Rs./kg, borax = 90 Rs./kg, zinc sulphate = 55 Rs./kg, and copper sulphate = 160 Rs./kg.

revealed that application of P sources significantly increased the grain yield of rice, the highest grain yield recorded with the application of a complex fertilizer source (20:20:0:13) followed by combined application of Mussouriee RP (MRP) + single superphosphate (SSP) (1:1 proportion). Relative agronomic efficiency (RAE) with insoluble low cost P source (MRP) was lower than the complex sources and SSP + MRP mixture (1:1), which had a significantly higher RAE compared to the sole source MRP (**Table 1**). The authors attributed better efficiency of SSP + MRP mixture to the combined effect, where SSP helped in meeting the immediate crop P requirement and the rest of the P requirement was met from the slow dissolution of MRP under acidic soil condition. Mitra et al. (1993) reported similar results in rice-groundnut cropping system in the alluvial soils of Puri district with strongly acidic pH (pH 5.3 to 5.5), where 1:1 mixture of SSP + Rajphos performed equivalent to SSP alone in terms of productivity of rice-groundnut cropping system in addition to minimizing P fixation while increasing the availability of P in acid soils.

From this study, combined application of SSP + MRP at 1:1 proportion may be considered as the right source of P in the acid soils due to the cumulative benefits of MRP in alleviating soil acidity and better comparable yield and relative agronomic efficiency of SSP + MRP over complex fertilizer source.

Right Rate of P Application

A study was conducted to evaluate the right P application rate to rice in an acidic soil (Inceptisol, pH 5.0) with sandy texture at the central farm of Orissa University of Agriculture and Technology for two consecutive seasons, namely the winter and summer rice seasons of 2005-06 (Pattanayak et al., 2008). The study consisted of seven treatments including a control, soil test-based recommended dose of fertilizer for rice (i.e., 290 kg N, 170 kg P_2O_5, 180 kg K_2O, 1 kg B, 7 kg Zn, and 14 kg Cu/ha, for two seasons), four treatments with P application rates from 25 to 100% of the soil test-based recommendation in increments of 25%, and a dose having 1.5 times the soil test-based recommended rates for N, P_2O_5 and K_2O (**Table 2**). All the treatments except control received a blanket dose of 5 t FYM/ha and 1,800 kg $CaCO_3$/ha.

Across the treatments, the cumulative yield of rice over two seasons varied from 4.9 to 13.9 t/ha, with highest grain yield of 13.9 t/ha recorded with soil test-based + 100% P (**Table 2**). Omission of P entirely from the fertilizer schedule resulted in 38% yield loss. The study also indicated that P application rate based on soil test resulted in higher nutrient uptake (N, P and K), which tended to plateau or decrease slightly with 1.5 times the soil test-based treatment. Increasing P application in 25% increments increased N and K recoveries considerably to a maximum of 53% for N and 141% for K at the soil test-based P recommendation. Highest net benefit (Rs. 62,497) per ha was also obtained in the soil test-based treatment (**Table 2**).

Based on the results of the study, it was inferred that right P application rates suggested for rice through the soil-test approach was responsible for a 5.2 t/ha grain yield response which raised the potential of a two crop rice system to 13.9 t/ha. In addition to improving rice yields, right rates of P application also increased the recovery efficiency of N and K while creating better economic benefits from hybrid rice cultivation.

Right Time of P Application

While growing crops in acid soils, timing of P application plays a critical role in improving the crop yield and recovery efficiency of applied P. Mitra et al. (1993) conducted a study on timing of P application in rice-groundnut cropping system grown in an acid soil, with P being applied to rice or groundnut grown during the rabi (winter) season. Results revealed that REY (Rice Equivalent Yield) of rice-groundnut cropping system was higher when P was applied to groundnut during winter season (8.3 t/ha) than the application of P to rice grown during the winter season (7.7 t/ha), showing 8% yield increase due to application of P to groundnut. The higher yield in P application timing to groundnut-rice system over the rice-groundnut system is due to higher P uptake (17.6 kg/ha) and higher recovery of applied P (19%), which are 23 and 55% higher than the rice-groundnut system, respectively (**Table 3**). Singh and Singh (2001) reported that rice can generally meet its P requirement utilizing the residual P from an adequately fertilized preceding crop. In the current study, P applied to rabi (dry) season groundnut solubilized more P and the portion that gets fixed during rabi season groundnut becomes available to the following rice crop due to soil reduction during submergence. Misra and Pattananyak (1997) observed similar results in rice-groundnut cropping system grown in the acid alluvial soils of Puri district and reported that application of the entire dose of P to rabi groundnut resulted in improved recovery of applied P in the succeeding crop of rice due to the submergence effect which reduced ferric phosphate to ferrous phosphate and increased the availability of P to rice.

Right Placement of P

Right placement of P fertilizer depends on the P fixation capacity of the soil, P source used, soil P fertility level and tillage practices. In acid soils with high rates of P fixation and prevalence of low soil P fertility levels, banding of P fertilizer is more efficient compared to the broadcast method. Boman et al. (1992) studied the impact of banding P fertilizer with seed on the production of winter wheat forage and reported a two to four-fold increase in the forage yield. Band placement of P has a more immediate impact on alleviating soil acidity than liming, especially under arid conditions, where activation of lime can take a significant amount of time, upwards of one year. Kaitibie et al. (2002) reported superior yield of winter wheat forage with band placement of P over incorporation of lime. For the farmers of Odisha growing second crop in the winter season, the time between the harvest of kharif crop and planting of rabi crop can be quite short and application of lime or any such ameliorating material may not get enough time for activation for alleviating soil acidity. Under such situations, band placement of P fertilizes may achieve better results in addition to applying liming materials.

Band placement of P fertilizers is efficient compared to the broadcast method. Singh and Singh (2001) reported that banding of water-soluble P fertilizers below or near the seed makes the P-source readily available to the roots, reduces the extent of P fixation and improves the uptake by crops. The authors also reported that closer spaced crops (rice, wheat etc.) are benefited from banding, compared to wider spaced crops like maize. However, Abrol and Meelu (1998) reported that broadcasting and mixing P fertilizers to soil during rice transplanting was more effective compared to its placement, whereas, for wheat, results are overwhelmingly in favor of drilling and placing P fertilizers below the soil surface and into the root zone. Tandon (1987) reported wheat yield increase of 400 to 700 kg/ha when P was placed or drilled compared to its broadcasting. Vig and Singh (1983) reported that band placement of P in wheat increased the P use efficiency, which was 1.5 times greater than when broadcasting. In acid soils with extremely low pH and low available P, broadcasting finely ground RP or partially acidulated RP followed by its incorporation is recommended (Singh and Singh, 2001).

Summary

It is highlighted in the above discussion that P nutrition can be better managed in the acid soils of Odisha by applying the principles of 4R Nutrient Stewardship. Application of the right P fertilizer source, at the right rate, right time, and in the right place helped in improving crop yields, in addition to alleviating the negative effects of soil acidity. However, guidelines on practicing 4R for P management in acid soils is limited especially for right placement and there is a need to initiate studies for documenting the benefits of right placement of P fertilizers for the predominant crops grown in Odisha. BC-SA

Table 3. Evaluation of P application timing on rice-groundnut cropping system grown on acid soil.

	---- **Groundnut-Rice ----			---- **Rice-Groundnut ----		
P source*	*REY, t/ha	P uptake, kg/ha	Applied P recovery, %	*REY, t/ha	P uptake, kg/ha	Applied P recovery, %
Control	6.8	12.6	-	6.7	11.0	-
SSP	9.8	20.9	24.0	8.4	16.2	15.0
MRP	8.6	18.7	17.0	7.8	14.6	10.0
URP	8.2	18.0	16.0	8.0	15.3	12.0
Mean	8.3	17.6	19.0	7.7	14.3	12.3

Source: Mitra et al. 1993.
*SSP = single superphosphate, MRP = Mussouriee rock phosphate, URP = Udaipur rock phosphate.
*Rice Equivalent Yield. **P applied to first crop grown during the rabi (winter) season.

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