Phosphorus Management in Crops and Cropping Systems in India – A Review

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Low to medium soil test P levels across India have increased the need to address the deficiency of P in achieving economic crop production.

Phosphorus additions to soils are dependent on not only adequate supplies of N, but also K, S and micronutrients to address the growing issues of multi-nutrient deficiencies limiting crop yields.

Increasing cost of fertilizer P has focused attention on how to improve P-use efficiency in a way that optimizes both crop and economic responses.

Phosphorus (P) is essential for all forms of life and is equally important for its contribution in aiding the native soil fertility and sustaining it, especially under intensive agriculture. The economic challenges associated with increasing P fertilizer prices are driving the increased interest in improving P use efficiency (Sanyal et al., 2015). Moreover, transfer of soil P from cultivated land through erosion or runoff is a major cause of P-induced eutrophication in surface waters. A judicious site-specific P management strategy is required to ensure optimum crop yield with lesser environmental footprint.

Data on available P content of surface (0 to 15 cm) soil has been compiled from time to time (**Table 1**) that provide a measure of P fertility of Indian soils. Thus, soils of more than 90% of the districts represented low to medium P fertility categories, indicating the necessity of P fertilization to produce optimum crop yields. Although, it may not be rational to assess the changes in P fertility status over time from these data as districts and locations of sampling may differ considerably, these data clearly indicate that P fertility of most of the Indian soils continues to be extremely poor. A recent publication based on omission plot trials in the Indo-Gangetic Plains showed that average yield loss due to no application of P fertilizer could be 712, 969, and 853 kg/ha in rice, wheat, and maize, respectively (Jat et al., 2012). Also, wide inter-regional variations exist in P fertility of soils, which are often masked in summarized country-level reports.

Table 1. Phosphorus fertility status of Indian soils.

Reference	Districts studied	% of districts in fertility categories*		
		Low	Medium	High
Ramamoorthy and Bajaj (1969)	226	47	49	4
Ghosh and Hasan (1979)	363	46	52	2
Muralidharudu et al. (2011)	500	51	40	9

*A soil analyzing less than 10 kg P/ha (Olsen-P value) is categorized as low, between 10 to 25 kg P/ha as medium, and over 25 kg P/ha as high in P availability.

Several methods for determining available soil P have been developed to provide a basis for fertilizer recommendations (Fixen and Grove, 1990). Generally, the P soil test data are categorized in different fertility classes, based on soil fertility ratings (low, medium and high), proposed during the 1950s on the basis of magnitude of crop response to nutrient input. These ratings remained almost unchanged although the entire spectrum of agriculture has been transformed since then, particularly with respect to P removal and response pattern of exhaustive crop varieties. When crop responses to P application are similar for both 'medium' and 'low' P soils, as indicated by multi- locational on-farm experiments (**Table 2**), a fertilizer prescription formulated for such a 'medium' fertility soil would be essentially sub-optimal for a low fertility soil. Hence, these ratings need to be revised in the light of current crop responses to applied P on different soils, and used for interpretation of soil test data.

Table 2. Average response of wheat to 60 kg P_2O_5/ha in on-farm trials on the soils of low, medium and high fertility status.

Fertility rating	Districts	Trials	Response, kg/ha
Low	21	2,140	680
Medium	17	2,446	669
High	1	147	486

Source: Tiwari (2006)

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; B = boron; Zn = zinc.

Phosphorus Removal under Dominant Cropping Systems

On-farm studies conducted under the All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS, earlier AICRP-CS) have clearly shown that P uptake was maximum in crops when all the macro and micro-nutrients were applied in optimum amounts. Application of P along with N increased P uptake by 21 to 25% in rice-wheat, 10 to 13% in rice-rice, 30 to 34% in maize-wheat, 12 to 40% in pearl millet-wheat, and 23 to 26% in cotton-wheat system in *kharif* and *rabi* crops, respectively over N application alone. The added increase due to K over NP was 9 to 33% under different cropping systems. Skipping micro-nutrients resulted in 11 to 34% lower P uptake under these cropping systems. Comparatively lower P uptake under farmers' fertilizer management practice (FFP) may be ascribed to the continuous neglect of K, S and micro-nutrients (Singh et al., 2013). On Typic Ustochrept soils of Modipuram, combined use of 120 kg N and 26 kg P/ha in rice and wheat not only produced high yields compared with addition of N alone, but the agronomic efficiency and apparent recovery of fertilizer N and P in rice and wheat also increased significantly (Singh et al., 2010).

Sharp decline in yield with P omission in on-farm trial.

Phosphorus deficiency symptions on exposed, erosion-prone soil.

Phosphorus Management Strategies under different Cropping Systems

Fertilizer P management in rice-wheat system (RWS) is of particular significance because of distinct growing conditions of rice and wheat that lead to alternate anaerobic and aerobic soil environments. In rice, submergence creates reducing conditions, which leads to reduction of ferric phosphate to ferrous phosphate, resulting in a greater availability of P in the soil (Sanyal and De Datta, 1991). Organic acids formed under submerged conditions also solubilize phosphates. Hence, in RWS, application of fertilizer P to wheat produces a better residual effect on the following rice crop. Nevertheless, while summarizing the results of the then AICRP-IFS, no definite conclusion could be drawn as to whether P should be applied to wheat or rice or to both crops. On loamy sand soils of Ludhiana, flooded rice did not respond to applied P, but the subsequent wheat crop did. Fairly recent studies on similar soils have, however, shown that the best approach is to apply P to both crops (Singh et al., 2002). In sandy loam soils of Modipuram, skipping of fertilizer P to either crop resulted in significant yield loss over P application to both the crops (Dwivedi, 1994). In view of varying reports, skipping of P to rice in RWS would depend on soil type, its P supplying and buffering capacity, relative distribution of different forms of P in the soil, submergence regime and productivity level.

Site-specific nutrient management (SSNM) studies conducted under RWS for attaining 10 t/ha hybrid rice and 6 t/ha wheat grain yield indicated that a soil sufficient in available P for moderate system yield (6 t/ha rice and 5 t/ha wheat) immediately falls under P responsive category with increasing production targets. Accordingly, P requirements increased for both rice and wheat crops. Optimum P fertilizer rates (P-opt) ranged between 14.6 and 27.7 kg/ha for rice, and from 19.4 to 32.7 kg/ha for wheat at different locations. A tremendous increase in the agronomic efficiency of applied P (AE_p) in rice and wheat, such as 38.6 to 70.2 kg grain/kg P and 22.7 to 37.4 kg grain/kg P, respectively, was noted when all the deficient nutrients (macro and micro- S, Zn, B) were applied for attaining high yield targets. In the on-farm studies also, partial factor productivity (PFP_p) and AE_p were maximum with balanced NPK fertilization under different predominant cropping systems (**Table 3**). Conjunctive uses of S and Zn with P have pronounced effect on P responses and use efficiency in many crops at various locations of AICRP-IFS (AICRP-IFS, Reports). Studies conducted on direct application of ground phosphate rock (GPR) on neutral Typic Ustochrept revealed that instead of applying GPR at the recommended rate to each crop, heavy initial dressings of P rates, recommended for 4 to 6 rice or wheat crops, is a promising option. Inoculation with *A. awamori* culture, i.e., root-dipping of rice seedlings and seed treatment of wheat further improved P availability from GPR, annual productivity and net profits (Dwivedi et al., 2004).

Analysis of multi-location long-term experiments (LTEs), conducted under AICRP-IFS, indicated a highly significant (*p*

Table 3. Partial factor productivity and agronomic efficiency of P as influence by balanced fertilization under different cropping systems.

		Partial factor productivity of P, kg grain/kg P				Agronomic efficiency of P, kg grain/kg P			
	No. of	---- 1st crop ----		---- 2nd crop ----		---- 1st crop ----		---- 2nd crop ----	
Cropping system	trials	with N	with NK	with N	with NK	with N	with NK	with N	with NK
Rice-rice system	1,830	107.1	124.9	91.9	107.8	19.8	34.3	19.1	33.3
Rice-wheat system	1,805	90.4	100.8	56.6	65.1	23.5	31.0	14.5	21.8
Pearl millet-mustard system	212	54.4	59.1	44.8	49	13.0	20.2	12.6	15.6
Maize-wheat system	1,010	66.4	75.6	70.7	81.1	18.8	27.8	22.3	31.1
Soybean-wheat system	395	22.8	26.5	51.7	61.3	3.6	7.0	9.1	17.2
Pearl millet-wheat system	146	48.1	59.3	60.7	71.5	14.5	25.3	15.9	25.3
Cotton-wheat system	56	49.9	53.4	69.3	73	19.1	21.2	27.7	32.4
Rice-maize system	12	85.8	100.5	63.7	88.7	18.9	33.1	12.8	27.4

Source: AICRP-IFS, 2001-2010

< 0.01) increase in yield of rice with integrated use of fertilizers and manures, suggesting thereby the advantage of the integrated plant nutrient supply system (IPNS) over sole use of NPK fertilizers in sustaining crop yields. As traditional organic manures are not available in adequate amounts, possibilities of inclusion of legumes in RWS may become a viable option for efficient P management strategies. Studies conducted by Dwivedi et al. (2003) revealed that forage cowpea grown during post-wheat summer on residual soil fertility increased the AE_P by 139% in the subsequent rice crop, and by 55% in the following wheat crop, while improving the apparent recovery of P fertilizer by 9 to 13% in rice and wheat, besides raising wheat yield and soil organic matter content. In another study, substitution of pigeon pea in place of rice enhanced wheat yields and NP use efficiency, owing to a greater nutrient recycling through pigeon pea residues and reduction in sub-surface soil compaction (i.e., decrease in soil bulk density), leading to better root growth in succeeding wheat (Singh et al., 2010).

Recent studies, conducted in the Western Plain zone (Dwivedi et al., 2004; Singh et al., 2010), indicated that around 61% of large farmers (≥ 4 ha farm size) burn rice residue partially or completely in their field. In such situations, use of the Happy/Turbo seeder machine for wheat was found to be a better option, which recycles the whole rice residue without any yield penalty (AICRP-IFS Report, 2011-12). The other options like furrow-irrigated raised bed (FIRB), permanent raised bed (PRB) and zero-till seeding are promising options. Field experiments on Typic Ustochrept of Western IGP by Singh et al. (2010) revealed that the economic optimum doses of fertilizer N and P for wheat in the pigeon pea–wheat system were smaller (128 kg N and 28 kg P/ha) under permanent raised bed (PRB) as compared to flat-bed (FB) (152 kg N and 30 kg P/ha) owing to the increased N and P supply, greater P use efficiency and a better crop growth environment, along with higher Olsen P content under PRB planting.

Economics of P Fertilization

Phosphorus is the costliest among the major plant nutrients applied through fertilizers. Nonetheless, yield responses to fertilizer P are often substantial, making P application an economically remunerative option. On-farm studies conducted under AICRP-IFS revealed substantial net return on investment in P fertilizer [Rs. 8.05 to 16.72 per rupee invested (Rs/Re) in fertilizer P_2O_5] in different cropping systems during 2004-06. The P fertilizer price hike by 2.5 to 3 times during the recent time, however, led to decline in economic returns (1.47 to 5.17 Rs/Re in P_2O_5) (**Figure 1**). Amongst the cropping systems compared, lowest economic returns on P usage were obtained with pearl millet-mustard system. Although P application continues to be remunerative despite increased price of P fertilizer, the drop in economics of P fertilization in recent years underlined the significance of enhancing P use efficiency through adoption of appropriate management practices (Singh, 2013).

Summary

Soils vary widely in their capacities to supply P to crops in view of the fact that only a small fraction of the total P in soil is available to crops. Thus, the crop growth and yield are likely to suffer adversely unless soil is endowed with adequate native supply of plant-available P, or else the soil receives

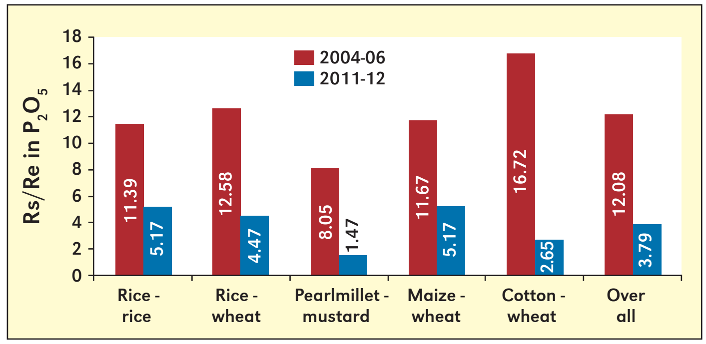

Figure 1. Change in net return invested on P (Rs/Re) due to increase in phosphate fertilizer prices between 2003-06 and 2011-12. Source: Singh, 2013.

readily available (inorganic) P fertilizers. The present article analyzes P management in important crops and cropping systems of India to underline the importance of fertilizer P application to support sustained high productivity for ensuring food security. BC-SA

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References

Annual Report of All India Coordinated Research Project on Integrated Farming Systems. 2001-2010. Project Directorate for Farming (earlier Cropping) Systems Research, Modipuram, Meerut.

Annual Report of All India Coordinated Research Project on Integrated Farming Systems. 2011-12. Project Directorate for Farming Systems Research, Modipuram, Meerut.

Dwivedi, B.S. 1994. Project Directorate for Cropping (now Farming) Systems Research, Modipuram, India. Annual Report (1992-94). 10-12 pp.

Dwivedi, B.S., A.K. Shukla, V.K. Singh and R.L. Yadav. 2003. Field Crops Res. 80: 167-193.

Dwivedi, B.S., V.K. Singh and V. Dwivedi. 2004. Aust. J. Exp. Agric. 44: 1041-1050.

Fixen, P.E. and J.H. Grove. 1990. *In*, Soil. Test. Pl. Analysis. (R.L. Westerman Ed.), SSSA, Madison, WI. 141-180 pp.

Ghosh, A.B. and R. Hasan. 1979. ISSS Bulletin, 12, 1-8.

Jat, M.L., D. Kumar, K. Majumdar, A. Kumar, V. Shahi, T. Satyanarayana, M. Pampolino, N. Gupta, V. Singh, B.S. Dwivedi, V.K. Singh, V. Singh, B.R. Kamboj, H.S. Sidhu, and A. Johnston. 2012. Indian J. Fert. 8(6): 62-72.

Muralidharudu, Y., K. Sammi Reddy, B.N. Mandal, A. Subba Rao, K.N. Singh, and S. Sonekar. 2011. GIS based soil fertility maps of different states of India. AICRP-STCR, IISS, Bhopal, pp 224.

Ramamoorthy, B. and J.C. Bajaj. 1969. Fert. News, 14(8), 25-36.

Sanyal, S.K., B.S. Dwivedi, V.K. Singh, K. Majumdar, S.C. Datta, S.K. Pattanayak, and K. Annapurna. 2015. Curr. Sci. 108(7): 1263-1270.

Sanyal, S.K. and S.K. De Datta. 1991. *In*, Adv. in Soil Sci. 16: 1-120. Springer-Verlag, New York.

Singh, B., Y. Singh, C.S. Khind, and R.K. Gupta. 2002. Better Crops International 16(1): 12-13.

Singh, V.K. 2013. FAI-IPI-IPNI Round Table on Balanced Fertilisation. July 2, 2013, FAI, New Delhi.

Singh, V.K., B.S. Dwivedi, A.K. Shukla, and R.P. Mishra. 2010. Field Crops Res. 116: 127-139.

Singh, V.K., B.S. Dwivedi, R.J. Buresh, M.L. Jat, K. Majumdar, B. Gangwar, V. Govil, and S.K. Singh. 2013. Agron. J. 105: 471-481.

Tiwari, K.N. 2006. Indian J. Fert. 2: 73-98.