Balanced Phosphorus Application for Improved Yield and Nutrient Use Efficiency under Rice-Wheat Systems of India

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The results of on-station, as well as on-farm experiments, distributed across contrasting locations and fields of India established that adequate use of P, with N and K, improves P use efficiency and production economics.

Application of P to both rice and wheat in rice-wheat system improved agronomic efficiency and partial factor productivity of phosphorus. Any decision to reduce P application to rice in rice-wheat system must be based on soil type, P supplying capacity, relative distribution of different forms of P in the soil, submergence regime and productivity level.

The Rice-Wheat cropping system (RWS) is the most important cropping system in India, covering 10 million hectares of cultivated land, and is the mainstay of food security in India. The yield gains in the RWS that were witnessed in 1960s and 1970s are not realized at present in most of the high productivity regions of India. In fact, since 1990, yield stagnation and declining annual growth rate of crop productivity have compelled farmers to apply increasing rates of fertilizers, particularly N fertilizer, to maintain the yield levels attained previously with less fertilizer use (Pagiola, 1995).

The important reasons assigned for such negative factor productivity are increasing multiple nutrient deficiencies led by imbalanced crop nutrition. Recent diagnostic surveys conducted on the Indo-Gangetic Plain region (IGP) of India reveals that fertilizer use in cropping systems is skewed towards N, P use was sub-optimal i.e., 25 to 48 kg P_2O_5/ha, while nutrients like K, S and Zn are largely ignored, resulting in deficiencies of these nutrients and declining factor productivity. For instance, analysis of over 4,000 soil samples from 14 locations of IGP indicated that 62% of soils fall under P responsive categories (≤25 kg/ha). As rice-wheat is essentially an irrigated production system, imbalanced use of N, without adequate P or other nutrient application, encourages NO_3-N loss (Dwivedi et al. 2003, Singh et. al., 2005), which may be a potential threat to groundwater quality used for drinking in rural areas. Inadequate P applications in crops results in negative P balance in the soil (Singh et al., 2005). Depletion of native P reserves, owing to low P additions over years in the RWS, led to an increased extent of P deficiency in these soils, and greater crop responses to P fertilizers. Soils deficient in plant-available P not only produce low yields but also reduce efficiency of other applied nutrients. Thus, there is an urgent need to seek strategies by which P fertilizers can be used more effectively in those cropping systems where P is currently deficient and where its use is economically feasible. The efficient use of fertilizer P is important for several other reasons such as, finite raw material resources for P fertilizer production, increasing cost of P fertilizer, decreasing crop P response in certain geographies, and environmental concerns associated with imbalanced use of P in crops. The present article analyzes on-farm and on-station data pertaining to different aspects governing the availability of native and applied P to the crops, and balanced P application on crop responses, nutrient use efficiencies and other associated gains to help develop judicious P management options in rice-wheat cropping system.

Phosphorus Management Strategies under Rice-Wheat System

The alternate anaerobic and aerobic growing environments of the rice-wheat system (RWS) require special attention to P management. Submerged growing environment in rice results in greater availability of P in the soil. 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 AICRP-IFS, no definite conclusion could be drawn as to whether P should be applied to wheat or rice, or to both crops. On farm studies conducted under (AICRP-IFS) revealed that combined use of 120 kg N and 26 kg P/ha in rice and wheat significantly increased the nutrient use efficiency in terms of partial factor productivity and agronomic efficiency of

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

Table 1. Partial factor productivity and Agronomic efficiency of P as influence by balanced NPK fertilization under rice-wheat systems (Source: AICRP-IFS report).

		Partial factor productivity of P, kg grain/kg P				Agronomic efficiency of P, kg grain/kg P			
	No. of	------ Rice ------		----- Wheat -----		------ Rice ------		----- Wheat -----	
Agro-climatic region	trials	with N	with NK	with N	with NK	with N	with NK	with N	with NK
Central Plateau and hills region	192	47.2	57.1	56	64.7	14.2	17.8	17.7	21.8
Eastern Plateau and Hill region	248	47.4	52.8	107.3	119.9	11	17.3	19.8	32.9
Eastern Plateau and Hill region	229	47.4	63.1	58.6	73.5	8.2	23.2	12.9	24.1
Gujrat Plains and Hills region	122	61.5	66.4	127.1	133.7	18.1	24.4	29.6	40.7
Middle Gangetic Plain region	345	53.8	62.2	74.6	86.3	18.2	24.2	23.9	32.6
Trans Gangetic Plain region	260	80.9	86.3	185.6	196.4	26.2	31.1	52.3	58.5
Upper Gangetic Plain region	234	62.3	70.1	74.7	84.8	14.7	23.8	19.8	27.9
West Himalayan region	137	65.8	74.9	73.7	83.4	14.7	21.8	18.2	26.3
Western Plateau and Hill region	38	43.4	52.7	56.4	64.4	5.2	12.3	17.6	14.6

fertilizer P in (**Table 1**). The magnitude of increase was more when balanced K application was included in the fertilization schedule. Further, the higher agronomic efficiency of P under wheat as compared to rice highlights the greater requirement of P use with the wheat crop. 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 et al., 1994). In view of varying reports, reduction of P use to rice in RWS would depend on soil type, P supplying 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 yield (6 t/ha rice and 5 t/ha wheat) immediately fell under P responsive category with increasing production targets. Accordingly P requirements increased for both rice and wheat crops. The optimum P fertilizer rates (P-opt) in this study ranged between 14.6 and 27.7 kg P/ha for rice, and between 19.4 to 32.7 kg P/ha for wheat at different locations. A significant increase in crop (rice + wheat) response to applied P along with higher benefit:cost ratio (2.1 to 14.6) under RWS was noted when all deficient nutrients (macro and micro- S, Zn, B) were applied for attaining high yield targets (**Figure 1**).

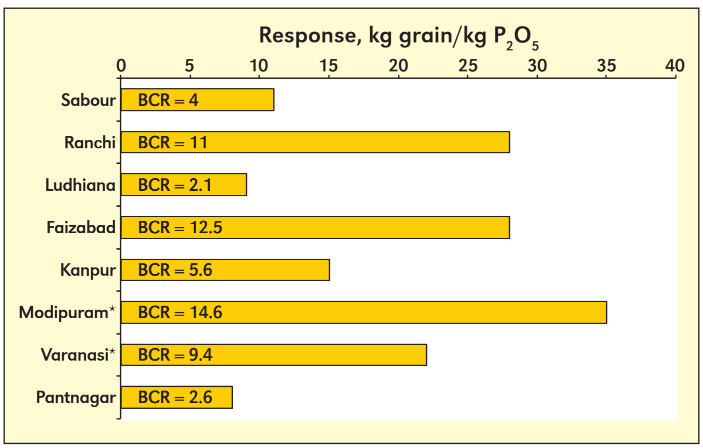

Figure 1. Response to P application in rice-wheat under site-specific nutrient management trials in the Indo Gangetic Plains. BCR = benefit to cost ratio.

Agronomic efficiency of P (AEP) was influenced by K application rates. At 33 kg K/ha, AEP in rice was in the range of 11.3 kg grain/kg P at Modipuram to 59.9 kg grain/kg P at Ranchi, and that in wheat varied from 9.7 kg grain/kg P at Palampur to 54.4 kg grain/kg P at Ludhiana (**Figure 2**). Increasing K application to rice or wheat had positive effect on AEP and it was maximum at 99 kg K/ha. Averaged over the locations, AEP for rice was 24.4, 44.7 and 47.4 kg grain/kg P, and 34.2, 47.0 and 50.9 kg grain/kg P for wheat at 33, 66 and 99 kg/ha K application rate, respectively. On the other hand, skipping K application had adverse effect on AEP, which was either low or even negative in some locations such as at Palampur, Ludhiana, Modipuram, Kanpur and Sabour in rice, and at Palampur in wheat crop (**Figure 2**).

The higher AEP in wheat as compared to rice may be explained as increased availability of active soil-P under flooded rice fields due to the dissolution of occluded-P (Fe and Al-phosphate) that generally results in low response of rice to

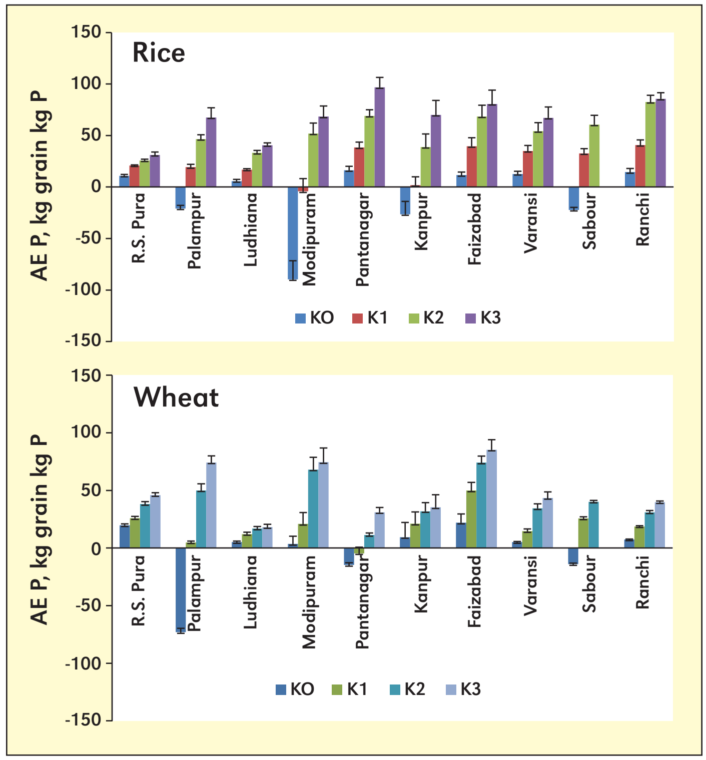

Figure 2. Agronomic efficiency (AE) P in rice and wheat as influenced by varying rates of K application (0, 33, 66, and 99 kg/ha K).

applied P. On the other hand, the aerobic growing environment and low temperatures during wheat growing seasons slows the dissolution of occluded P and decomposition of soil organic matter that reduces the availability of organic P, leading to relatively higher response to externally applied P. The increase in the availability of soil P on water logging is, however, not uniform in all soils (Tomar, 2000) and variable response, as seen in the current experiment, are often visible.

Apparent recoveries of P, average 28.8% across the locations for rice, were comparatively higher than that of wheat (25.6%), although large inter-site variations were seen (**Table 2**). For the rice-wheat system as a whole, the average apparent recovery of applied P was 27.2%.

Inclusion of legumes in RWS may become a viable option for efficient P management strategies. Studies conducted at

Table 2. Apparent P recovery efficiency (RE) in maximum economic yield plot fertilized according to SSNM under rice-wheat cropping system

Location	Rice	Wheat	Rice-wheat system
Sabour	28.6	26.9	27.8
Palampur	23.9	20.8	22.4
Ranchi	24.6	16.8	20.7
R.S. Pura	21.8	18.4	20.1
Ludhiana	30.6	29.1	29.9
Faizabad	30.9	30.2	30.6
Kanpur	38.3	36.1	37.2
Modipuram	31.8	27.6	29.7
Varanasi	28.4	24.5	26.5
Mean over location	28.8	25.6	27.2
C.D. at 5%	5.23	5.48	4.80

Table 3. N and P use efficiency in rice and wheat as influenced by inclusion of forage cowpea in RWS.

Rates, kg/ha	Agronomic efficiency of N, kg grain/kg N: Summer fellow	Agronomic efficiency of N, kg grain/kg N: Summer cowpea	Agronomic efficiency of P, kg grain/kg P: Summer fellow	Agronomic efficiency of P, kg grain/kg P: Summer cowpea	Recovery efficiency of N, %: Summer fellow	Recovery efficiency of N, %: Summer cowpea	Recovery efficiency of P, %: Summer fellow	Recovery efficiency of P, %: Summer cowpea
Rice								
$N_0 P_0$	-	-	-	-	-	-	-	-
$N_0 P_{26}$	-	-	11.5 ± 0.42	31.20 ± 0.85	-	-	11.61 ± 0.26	15.57 ± 0.60
$N_{120} P_0$	21.33 ± 0.55	16.67 ± 0.61	-	-	34.8 ± 0.91	35.30 ± 1.35	-	-
$N_{120} P_{26}$	23.92 ± 0.82	22.08 ± 0.80	23.50 ± 0.65	56.2 ± 1.58	36.4 ± 1.00	41.20 ± 1.47	22.73 ± 0.63	25.04 ± 0.79
Wheat								
$N_0 P_0$	-	-	-	-	-	-	-	-
$N_0 P_{26}$	-	-	8.50 ± 0.22	14.20 ± 0.41	-	-	11.17 ±0.32	12.60 ±0.43
$N_{120} P_0$	18.25 ± 0.76	18.25 ± 0.81	-	-	42.3 ± 1.15	38.30 ± 0.95	-	-
$N_{120} P_{26}$	25.75 ± 0.74	29.67 ± 0.79	43.10 ± 1.23	66.90 ± 1.95	54.50 ± 1.65	61.70 ± 2.02	27.95 ±0.77	30.35 ±0.85

Modipuram revealed that forage cowpea grown during post-wheat summer on residual soil fertility increased the AEP 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. The effect on P use efficiency was more pronounced when balanced N and P were applied together (**Table 3**).

After wheat harvest, the NO_3-N content below the 30 cm soil profile-depth was lower in N and P fertilized plots compared with those receiving N alone, and also lower in summer cowpea plots compared with summer fallow (**Figure 3**). It is, however, possible that a better-established wheat crop in summer cowpea treatments absorbed NO_3-N from lower profile-depths, which ultimately resulted in low NO_3-N content at these depths, as compared to summer fallow treatments. If NO_3-N content in lower profile-depths is considered as an indicator of N leaching, the results of this study inferred that the extent of N leaching can be minimized with adequate P fertilization at recommended rates to both rice and wheat, as also with inclusion of summer cowpea. In the intensively cultivated areas of northwestern India, particularly those managed under irrigated rice-wheat system with heavy fertilizer N dressings, leaching of NO_3-N is a serious concern (Aulakh and Singh, 1997) that could be addressed through appropriate P fertilization.

In another study, substitution of pigeon pea in place of rice enhanced wheat yields and NP use efficiency, owing to 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., 2005). In this study, increasing P rates in wheat had more root

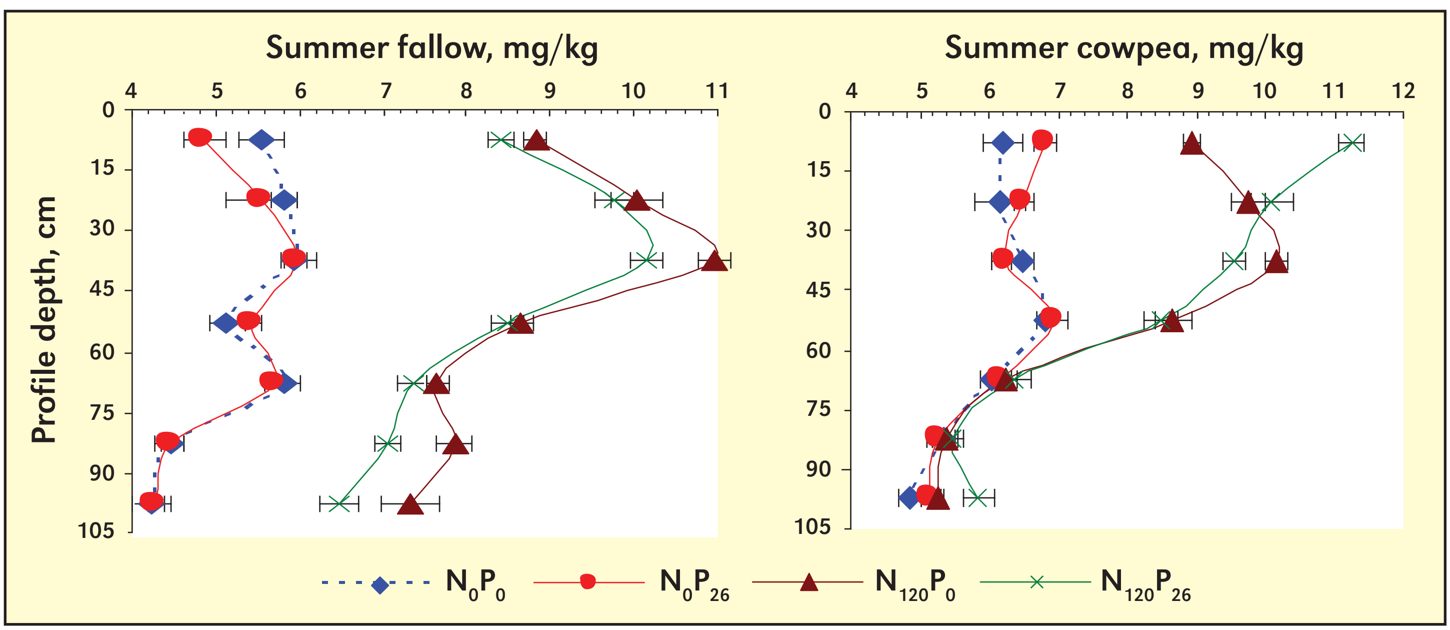

Figure 3. Effect of N P fertilization and cropping system on distribution of nitrate-N in soil profile under rice-wheat system.

proliferation in terms of root mass density (**Figure 4**), which helped in trapping nutrients from lower soil profile and made it available to the crop.

Conclusion

The result of on-station as well as on-farm experiments distributed across contrasting locations and fields of India established the importance of adequate use of P with N and K to match crop need for high yield targets and for achieving better economics of production. Balanced fertilization considering all deficient nutrients and with inclusion of legume in RWS further improves response to P application, nutrient use efficiency along with better root growth. BC-SA

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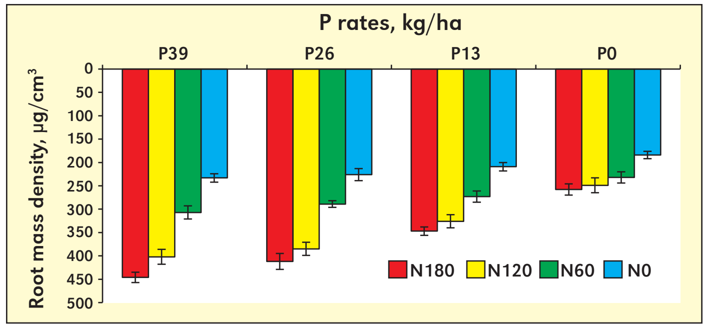

Figure 4. Effect of P application on root growth of wheat.

References

Aulakh, M.S., B. Singh. 1997. Nutr. Cyc. Agroecosyst. 47, 197-212.
Dwivedi, B.S. 1994. Annual Report (1992-94). PDCSR, Modipuram, India, pp. 10-12.
Dwivedi, B.S., K. Shukla Arvind, V.K. Singh, R.L. Yadav. 2003. Field Crops Res. 84, 399-418.
Pagiola, S., 1995. Environmental Economics Series Paper No. 15, World Bank Environment Department, Washington, DC, USA.
Singh, V.K., B.S. Dwivedi, A.K. Shukla, Y.S. Chauhan, and R.L. Yadav. 2005. Field Crops Res. 92, 85-105.
Singh, V.K., B.S. Dwivedi, A.K. Shukla, and R.P. Mishra. 2010. Field Crops Res. 116, 127–139
Tomar, N.K., 2000. J. Indian Soc. Soil Sci. 48, 640-673

Crop Nutrient Deficiency Photo Contest Entries Due December 9, 2015

This year, the deadline for submitting entries to the annual IPNI contest for photos showing nutrient deficiencies is early December. Remember, our **Feature Crop** category for 2015 is **Root and Tuber Crops** (e.g., Potato, Sweet Potato, Cassava, Carrot, Beets, etc).

Our prizes are as follows:

- US$300 First Prize and US$200 Second Prize for Best Feature Crop Photo.
- US$150 First Prize and US$100 Second Prize within each of the N, P, K and Other Nutrient categories.
- Note that all winners are eligible to receive the most recent copy of our USB Image Collection. For details on the collection please see http://ipni.info/nutrientimage-collection

Entries can only be submitted electronically to the contest website: www.ipni.net/photocontest. Winners will be notified and announced in early 2016. Look for results posted on ipni.net. BC

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Iron deficiency in cassava.