Phosphorus Management in the Rice-Wheat Cropping System of the Indo-Gangetic Plains

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Soils of the rice-wheat cropping system belt in the Indo-Gangetic Plains are mostly low to medium in P fertility. Inadequate P fertilisation is one of the major barriers to achieving targeted yields of rice and wheat. The general recommendation and practice of applying P to wheat and raising rice on residual P fertility is partly responsible for this. Research suggests 90 to 100 kg P_2O_5/ha/yr should be applied in the system, about two-thirds to wheat and one-third to rice. This recommendation will go a long way in increasing rice and wheat production. Any future food production increases will require additional P use. The chance of a sizeable supplementation from other sources, such as manure and crop residues, appears rather limited at this time.

The rice-wheat cropping system (RWCS) is the backbone of India's food security. The magnitude of the contribution of RWCS to the country's food security can be gauged from Punjab alone, which has less than 2% of the country's cultivated land, and provides 60% of the wheat and 40% of the rice to the Public Distribution System and national buffer stocks (Swaminathan, 2007). As a matter of fact, the Punjab-Haryana-Western Uttar Pradesh (UP) crescent has been the heartland of the Green Revolution (GR). This non-traditional rice region, where wheat was the principal crop and money earner has seen rice emerge as the money maker. Further, a large number of farmers are now growing *Basmati* rice which fetches premium prices.

The Indo-Gangetic Plain (IGP) came into existence as a result of continuous deposition of alluvium from the hills and mountains from both sides of the plains – the Himalayas in the north and Deccan Plateau in the south. Soils of the IGP are Ustochrepts, Aquents, Naturstalf, and Hapludolls (*Tarai* region). Soil texture varies from sandy loam at Ludiana to silty loam at Pusa (Bihar). There are large lowland patches of heavier soils (silty clay loam to clayey) in almost all states in the IGP where RWCS is practiced. The annual rainfall in the IGP varies from 650 mm at Ludhiana in the west to 1,666 mm at Barrackpore in the east **(Table 1)**.

The RWCS is spread over five states in the IGP, namely, Punjab, Haryana, UP, Bihar, and West Bengal. These states are under four agro-climatic regions (ACRs) including: Trans-Gangetic Plain covering Punjab and Haryana (ACR VI); Upper-Gangetic Plain covering western UP (ACR V); Middle-Gangetic Plain covering eastern UP and Bihar (ACR IV); and Lower-Gangetic Plain covering West Bengal (ACR III). The area under RWCS in the IGP is about 9 million hectares (M ha). There is an additional 1.5 to 2 M ha outside the IGP in the states of Himachal Pradesh, Uttarakhand, Madhya Pradesh, and Rajasthan.

There was a trend for total P and Olsen P to increase moving eastwards within the IGP before the GR (**Table 2**). However, after the GR, and due to relatively higher fertiliser P application in Punjab and West Bengal, the Olsen P and P fertility index in the IGP shows a trough-like situation, being medium at both the ends and low in the centre…UP and Bihar (**Table 3**) (Motsara, 2002). Organic P continues to be higher as one moves eastward due to higher organic C status in the east (**Table 2**). For inorganic P, Ca-P forms dominate,

Table 1. Soil characteristics at some research centres in IGP.

Research centre (State)	Soil type	Soil texture	Annual rainfall, mm	Organic C, %	Olsen P, mg/kg
Ludhiana (Punjab)	Typic Ustochrept	LS[1]	650	0.31	5
Karnal (Haryana)	Aquic Natrustalf		700	0.30	15
Pantnagar (UP)	Hapludoll	SiCL	1350	1.48	18
Kanpur (UP)	Udic Ustochrept	SL	818	0.39	6
Faizabad (UP)	Udic Fluaquents	SiL	1100	0.37	6
Pusa (Bihar)	Ustochrept	SiL	1100	0.42	20
Barrackpore (WB)	Eutrochrept	SL	1666	0.71	19

[1] LS = Loamy soil; SL = sandy loam, SiL = Silty loam; SiCL = Silty clay loam.
Source: Ladha et al., 2003.

Table 2. Distribution of different forms of P in some IGP soils.

Location	Total, mg/kg	Saloid P	Al-P	Fe-P	Ca-P	Organic P	Occluded P	Olsen P, mg/kg	P-fixing capacity	Organic C, %
		- - - - - - - -	- - - -	- - -	% of total P	- - -	- - - - - - - -			
Ludhiana (Punjab)	435	1.3	3.7	4.6	33.8	8.7	48.0	6	11.2	0.31
Kanpur (UP)	539	0	1.5	1.1	37.9	13.5	45.9	6	60.0	0.39
Pusa (Bihar)	583	0.5	0.7	0.3	59.8	21.4	17.2	9	30.9	0.45

Source: Khanna and De Datta, 1968.

Abbreviations and notes for this article: P = phosphorus; Ca = calcium; C = carbon; N = nitrogen; K = potassium; Zn = zinc; Al = aluminum; Fe = iron; S = sulphur; DAP = diammonium phosphate; SSP = single superphosphate; C.D. = Critical Difference; M t = million metric tons.

Table 3. Phosphorus fertility status of soils in RCWS states.

State	Samples analysed	% samples in the category			P fertility index[1]	Category
		Low	Medium	High		
Punjab	3,48,096	29	49	22	1.93	Medium
Haryana	2,73,459	81	18	01	1.20	Low
UP	8,07,424	71	26	03	1.32	Low
West Bengal	44,284	34	27	39	2.05	Medium

Note: Data over several years; Bihar data not available.

[1] P fertility Index (for the state) = $\frac{(Sl \times 1) + (Sm \times 2) + (Sh \times 3)}{St}$

Where, 'St' is the total number of samples analysed; Sl, Sm, and Sh stand for the number of samples analysing low, medium, and high.

Source: Motsara, 2002.

and again increase moving eastward. These generalizations do not hold true for Hapludolls in the *tarai* region of Uttarakhand, which have higher organic C and Olsen P content (**Table 1**).

Submergence of rice fields immediately after P application leads to a flush of available P (Kirk et al., 1990). However, continued submergence can reverse the effect as P is precipitated in the oxidised rhizosphere and sorbed on the solid phases during reduction (Patrick and Mahapatra, 1968) and may further immobilise P (Simpson and Williams, 1970). Mandal (1979) also pointed out that increased availability of P on submergence is not uniform in all soils; it may be fairly high in some soils, while negligible in others. A number of factors are responsible for this differential behaviour of soils. These include inorganic P forms, pH, calcium carbonate, and organic C content. In general, submergence leads to increased availability of soil P due to dissolution of occluded P (Patrick and Mahapatra, 1968) and this has led to the general belief that on the same soil, rice responds to applied P lesser than upland crops. However, in the RWCS subsequent drying during the wheat season reduces P availability (Sah and Mikkelsen, 1989; Sah et al., 1989ab). Thus, repeated submergence and drying over the years leads to low P fertility and an increased response to applied fertiliser P as reported by Kumar and Yadav (2001).

Most information on source, method, and time of P application in India is available for the individual rice and wheat crops rather than for the RWCS. Experiments showed that 50 to 70% water soluble P product was required in P fertilisers for wheat (Hundal and Sekhon, 1980; Yadav and Verma, 1983) and 30 to 50% for rice (Sekhon, 1979). Broadcasting and incorporation at final puddling is the only possible and practical application method for rice, while sub-surface placement is the proper method for P application in wheat (Sinha and Ray, 1969; Ray and Seth, 1975, Tandon, 1987). Most P in rice, as well as wheat, is applied at transplanting/sowing. Split application of P in rice or wheat has shown no advantage over a single application at transplanting/sowing (Shukla and Chaudhary, 1977; Katyal, 1978; Singh and Singh, 1979). However, if P is not available at sowing it can be topdressed at the first irrigation in wheat (Singh, 1985).

Besides being one of the most important major plant nutrients for Indian agriculture, P is the costliest. For example, the recent price was Rs.16.22/kg P_2O_5 as DAP and Rs.16.25 to 26.88/kg as SSP, as compared to Rs.10.50/kg N as urea and Rs.7.43/kg K_2O for muriate of potash. Thus, a recommendation of 100 kg P_2O_5/ha amounts to an investment of Rs.1,622/ha for P alone – a scenario which many farmers can not readily afford. These situations suggest a need to explore possibilities of supplementing P from the other sources. The available sources discussed briefly below highlight the constraints related to the use of other sources of P in Indian agriculture.

Direct application of finely ground phosphate rock (GPR) has received considerable attention (Prasad and Dixit, 1976; Mathur and Sarkar, 1998). Several strategies for increasing the efficiency of GPR have been suggested, including mixing of GPR with pyrites (Tiwari, 1979; Sharma and Prasad, 1997), inoculating with phosphate solubilising organisms (PSO) (Chhonkar and Subbarao, 1967), use of VAM (Baon and Wibawa, 1998), use of PSO with crop residues (Sharma and Prasad, 2003), and mixing with soluble P fertilisers (Mishra et al., 1980; Govil and Prasad, 1972). Application of GPR with PSO, with or without crop residues seems to be an acceptable technique. The only problem is, where is the indigenous GPR? During 2005-06 only 257,000 t of PR (Jhabua 137; Sagar 112; Purulia 8) was mined in India. These are poor quality phosphate rocks containing 12 to 15% P_2O_5. Also, GPR has to be applied at rates 2 to 3 times that of fertiliser P.

Organic manures have also received considerable attention and integrated nutrient management (INM) has been widely discussed (Hegde, 1998; Prasad, 2002; Prasad et al., 2003; Gupta et al., 2006). The problems that remain are product availability, high costs with transportation, and low P contents.

Prasad et al. (2004) reported that about one-fourth of the P taken up by the rice crop remained in the straw, while it was one-fifth of the total P uptake in the case of wheat straw. Thus, a small part of the P requirement could be met by the incorporation of rice/wheat residue. Sharma and Prasad (2002) reported that the contribution of crop residue P to a growing crop can be further increased when the residue is applied with a culture of cellulolytic fungus as judged by the Olsen P in soil. Advantages of incorporation of rice/wheat residue in the RWCS have been reviewed by Samra et al. (2003).

Before mechanisation of agriculture set in on the RWCS belt (only in the western parts viz., Punjab, Haryana, and Western UP) humans, cattle, and cereal crops formed a unique agro-socio-ecosystem. However, after mechanisation, cattle are less common and residue management becomes a serious problem because of the very short period (about 2 to 3 weeks) between rice harvesting and wheat sowing – leading many farmers to burn rice residues in the field.

According to Sarkar et al. (1999) about 37.87 M t of rice and wheat residue is available for recycling in the RWCS - equivalent to about 69,000 t P_2O_5. However, incorporation of rice/wheat residue involves an additional application of 15 to 20 kg N/ha to overcome the initial setback to the crop due to immobilisation of native soil N (Samra et al., 2003). The other alternative is to mix cereal and legume residues (Sharma and Prasad, 2001).

A sustainable P management strategy within the RWCS must ensure high and sustainable foodgrain production, high net profit, build-up of native available soil P, and avoidance of over fertilisation with P that may make nutrients such as Zn unavailable to crops.

The increased availability of native soil P under submergence and some data generated by researchers **(Table 4)** led to the belief and recommendation to RWCS farmers that 60 kg P_2O_5/ha may be applied to wheat and rice could be well-grown on residual fertility (Singhania and Goswami, 1974; Meelu and Rekhi, 1981) This recommendation was made despite the fact that Formoli et al. (1977) reported that both rice and wheat responded to P application, and Kolar and Grewal (1989) reported that application of 30 kg P_2O_5/ha to both rice and wheat gave higher total grain production than application of 60 kg P_2O_5/ha to wheat alone.

Table 4. Effect of application of P to rice or wheat or both on the productivity of RWCS.

kg P_2O_5/ha applied		Grain yield, t/ha		
Wheat	Rice	Rice	Wheat	Rice + Wheat
60	0	6.6	4.1	10.7
0	60	6.5	2.4	8.9
60	60	6.5	4.2	10.7
0	0	3.9	2.3	6.2
C.D. (5%)		0.39	0.30	

Source: Gill and Meelu, 1983.

A major factor responsible for recommending P to wheat only in the RWCS was the fact that dwarf high yielding wheats were introduced before the introduction of high yielding rice varieties, and dwarf wheats showed a good and distinct response to P fertilisation which was not recorded for tall Indian wheats. There were three main factors responsible for this, including: high yields, a shorter root system at the initial growth stages (associated with shorter stems in dwarf wheats which limited their native soil P foraging capacity), and lower temperatures (optimum sowing date for dwarf wheats was mid-November, later than the traditional mid-October) reducing the rate of decomposition of soil organic matter, resulting in lesser availability of soil organic P. For example, the mean minimum temperatures at Delhi in mid-October and mid-November are 18 °C and 10 °C, respectively.

Interestingly, some recent (1999-2000) data on the response of rice and wheat **(Table 5)** conducted under the Project Directorate for Cropping Systems Research, Modipuram on farmer fields show that both rice and wheat respond well to P fertilisation. In fact, the response of rice to P was more than wheat in Punjab, UP, and Bihar. These data also show that response to P was better with NK fertilisation than with N alone, highlighting the importance of balanced fertilisation (Prasad and Power, 1994; Tiwari, 2002; Prasad et al., 2004).

Table 5. Response (kg grain/kg P_2O_5) of kharif rice and wheat to P fertilisation in IGP on farmers' fields (average over 3 years 1999-2002).

	Rice				Wheat			
		Control yield,	Response over			Control yield,	Response over	
State	Trial #	t/ha	Over N	Over NK	Trial #	t/ha	Over N	Over NK
Punjab	48	4.1	15.6	16.3	48	3.1	11.2	11.7
Haryana	24	3.4	10.3	11.3	70	2.0	13.0	14.1
UP	147	1.2	5.9	5.9	137	0.9	4.2	5.3
Bihar	22	1.6	14.6	15.5	46	1.0	8.6	12.9
West Bengal	64	1.7	8.6	10.4	–	–	–	–

Source: Indian Agricultural Statistics Research Institute, New Delhi.

Table 6. Additional P fertiliser needs of RWCS of IGP for foodgrain production of 294 M t by 2020 (additional production of 84 M t).

% share[1] expected from RWCS of IGP	Additional production needed, M t	Additional P_2O_5 needed[2], '000 t
25	21	178.5
50	42	357.0
75	63	535.5
100	84	714.0

[1] % share of total 84 mt

[2] Prasad et al. (2004) based on a number of studies at New Delhi reported an uptake of 8.2 kg P_2O_5/t of rice and 8.7 kg P_2O_5/t of wheat. An average value of 8.5 kg P_2O_5/t of grain is therefore taken for these calculations.

Using long-term RWCS experiment data at Ludhiana, Yadvinder-Singh et al. (2000) have concluded that the normal practice of applying 60 kg P_2O_5/ha to wheat only resulted in lower P build-up in soil, a negative P balance, a decline in available Olsen P, lower agronomic efficiency, and lower recovery of P applied to wheat. They recommended an application of 74 kg P_2O_5/ha to wheat and 34.5 kg P_2O_5/ha to rice for optimum productivity in the RWCS. These data thus support the conclusions drawn earlier by Yadav et al. (1998) and Kumar and Yadav (2001) from a long-term experiment on RWCS at Faizabad (UP) that over a long period both rice and wheat respond to P. **Thus, the general recommendation for the IGP would be an application of 90 to 115 kg P_2O_5/ha/yr to RWCS...about two-thirds to wheat and one-third to rice.**

Phosphorus management in the RWCS should therefore be considered as a long-term investment in soil fertility for sustained production. In contrast to N, it is more effective and practical to prevent P deficiency than to treat P deficient crops.

As per the current general recommendation of 95 to 115 kg P_2O_5/ha in the RWCS, the P need of 9 M ha works out to 0.85 to 1.03 M t of P_2O_5. The estimated demand for foodgrain for India is 294 M t/yr by 2020 (Kumar et al., 1998). Against the present production of about 210 M t, 84 M t/yr of additional foodgrain is required from the same cultivated area. Depending upon the share designated from the RWCS belt in the IGP, the additional P requirement for this area may vary from 178,000 to 714,000 t of P_2O_5 **(Table 6).** Thus, by 2020 the P requirement of this RWCS is likely to be 0.9 to 1.7 M t of P_2O_5, about one-third more P than is consumed currently.

Increased production in the RWCS is possible because potential yields are twice or more those currently grown, especially in ACRs III, IV, and V **(Table 7).**

However, the trend in total RWCS productivity from 1985 to 1992 and beyond is negative. One of the causes for this situation is imbalanced NPK fertilisation (Tiwari, 2002; Prasad et al., 2004) and emerging deficiencies of micronutrients such as of Zn (Takkar et al., 1989; Prasad, 2006), and increasing S deficiency (Biswas et al., 2004; Tewatia et al., 2007). If adequate measures are taken to overcome these nutrient imbalances and deficiencies, the RWCS in the IGP can be sustained and ACR IV (Eastern UP and Bihar) can become another granary similar to the Punjab-Haryana-Western UP crescent. BC-INDIA

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Table 7. Present and potential grain yields of rice and wheat in different agro-climatic regions.

Agroclimatic region	Present yields, t/ha[2]			Potential yields, t/ha[3]		
	Rice (R)	Wheat (W)	R+W	Rice (R)	Wheat (W)	R+W
ACR VI[1]						
Haryana	4.5-6.0	3.5-4.0	8.0-10.0	10-10.7	7-7.7	17-18.4
Punjab	5.2-6.7	3.5-4.5	8.7-11.2	10-11.7	7-8	17-19.7
ACR V	3.0-4.5	2.5-3.5	5.5-8	10-10.7	6.7-7.2	16.7-17.9
ACR IV	2.2-3.7	1.5-2.5	3.7-6.2	9-9.7	6.7-7.2	15.7-16.9
ACR III	3.0-3.7	2-2.5	5.0-6.2	7.2-7.7	4.7-5.2	11.9-12.9

[1] Rice as paddy (66% rice after shelling).
[2] Source: Narang and Virmani, 2001.
[3] Agarwal, et al., 2000.

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