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Crop Response and Economics of Phosphorus Fertiliser Application in Rice, Wheat and Maize in the Indo-Gangetic Plains

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Phosphorus (P) is one of the major essential plant nutrients. Physiological processes and yield of cereals are adversely affected in soils deficient in phosphorus. Phosphorus deficiency is widespread in Indian soils and response of cereals to applied P is often spectacular. P use has increased significantly with increasing food grain production in India. Recent increase in P fertiliser cost, however, has raised concerns about the profitability of P application in cereals. Results of on-farm P omission plot experiments conducted across the Indo-Gangetic Plain indicated an average P response of 712, 969 and 853 kg/ha in rice, wheat and maize, respectively. This suggests that skipping P application or blanket reduction in P application rates across a region or the country would adversely affect cereal production in India. Economic assessment based on application rates, nutrient response, cost of phosphate and minimum support price of the cereals showed return on investment (Rs/Re) of 2 in all scenarios. A mechanism of optimizing return on investment in P fertiliser in changing fertiliser price scenario and variable crop P response situations was highlighted. In general, a crop response based site specific P management strategy would help in maximizing yield and profitability of major cereals under increasing fertiliser price scenario.

Phosphorus (P) is one of the major plant nutrients that directly or indirectly affect all plant physiological processes. It is a key component of energy metabolism and biosynthesis of nucleic acids and membranes. Many basic biochemical processes such as photosynthesis and respiration are energized by inorganic phosphate or its organic derivatives. In addition, concentration of phosphate in the chloroplast determines the transport of phosphorylated sugars and synthesis of starch (9). In spite of its importance in biology, plants strive hard to obtain this essential nutrient from the rhizosphere. This is primarily due to low availability of P in many natural ecosystems (1). P deficiency is considered to be one of the major limitations for crop production particularly in low-input agricultural systems around the world. It is estimated that globally 5.7 billion hectares of cultivated land is deficient in P for achieving optimal crop production (2). It is a significant concern in the highly weathered and volcanic soils of the humid tropics, and sandy soils of the semiarid tropics (10). Results from long-term experiments in India indicated that inadequate nutrient application led to remarkable depletion in soil fertility in intensive cropping systems (12). Phosphate fixation increases significantly under acid soil conditions, which affects nearly 26% of the world's soils (4). While the low availability of P in many parts of the world is one of the leading causes for poor crop yields, excess application of manure and fertilisers in high runoff and erosion prone ecosystems has become a significant source of water pollution (10).

P availability has become a global problem, although it may vary from severely P deficient tropical soils to many temperate soils that are loaded with P (9). And their effect could range from depressed crop productivity due to deficiency to a threat to the environment due to nonpoint source pollution and nutrient enrichment of water bodies from excess P.

A summary of information on the P fertility status of Indian soils (7), based on compiled data from more than 3 million analysed samples from across the country, suggests that about 80% of the samples were low to medium in P fertility and would require supplemental and balanced P fertilisation. However, due to the time lag between soil analysis and release of the results, the soil data may no longer reveal the current soil fertility status. Between 1999-2000 and 2010-11, P_2O_5 consumption in India has almost doubled (increase from 4.8 million tonnes to about 8.0 million tonnes). During the same period, foodgrain production in the country has increased from 210 mt to about 252 mt in 2011-12 (5). Near doubling of the P fertiliser consumption may have contributed more to supporting the increased production of foodgrains and other crops rather than contributing significantly to long-term fertility gains in the deficient soils that were reported (7). Lack of a spatially distributed database on soil fertility, which can be periodically updated with new soil data, is a constraint to realistically follow the changing trend of soil fertility in India. This paper summarizes the yield response to P fertiliser (P response) of rice, wheat and maize from on-farm omission plot experiments conducted in 2009-2011 across different growing environments in the Indo-Gangetic Plains (IGP) region. P response provides an estimate of yield losses due to P omission as compared to an ample NPK treatment in each location. The three cereal crops covered in this study largely contributes to food security in India and consumes a major share of nitrogen (N), phosphorus (P) and potassium (K) utilized for agricultural production.

OBJECTIVES

Rice, wheat and maize are grown in different types of soils, cropping system and agro-ecologies across India. Such variability in land characteristics and growing environments is reflected in the productivity (attainable yield) and subsequently in nutrient requirement by these crops. This highlights the necessity to integrate crop response data in fertiliser decision support for increased productivity, higher economic return and better environmental stewardship. We undertook the current study to estimate: (a) response of cereals to P application in the IGP, (b) economic returns on application of P fertiliser, and (c) profitability of P application in changing fertiliser price scenario.

MATERIALS AND METHOD

On-farm trials were established across the IGP to capture the nutrient response of crops under variable soil and growing environments. Variability is inherent in agricultural production environments due to long-term genesis of soils as well as management differences, at a more local level. The cereal growing regions of the vast IGP have farming systems that differ in size of farms, cropping system and resource availability to farmers that compounds the inherent soil genetic variability. The current study, conducted in 2009-2011 by International Plant Nutrition Institute (IPNI) and International Maize and Wheat Improvement Centre (CIMMYT) under the Cereal Systems Initiative for South Asia (CSISA), covered the states of Punjab, Haryana, Uttar Pradesh, Bihar and West Bengal. The general characteristics of the sites are given in **Table 1**.

Table 1 – Characteristics of the experimental sites

State	Districts	Agro-climatic Zone	Soil texture	Average annual precipitation (mm)	Cropping system	Crops studied	Ecology
Punjab	Ludhiana, Amritsar, Gurdaspur, Sangrur, Fatehgarh Sahib	Central Plain Zone to Sub-Mountain Undulating Zone	Sandy loam to silty loam	600-1020	Rice-Wheat, Cotton-Wheat	Rice and Wheat	Irrigated
Haryana	Karnal, Kurukashetra, kaithal, Ambala, Yumnanagar	North Western plain zone	Sandy loam to clay loam	400-600	Rice-Wheat	Rice and Wheat	Irrigated
Uttar Pradesh	Agra	South Western Plain Zone	Sandy loam	650	Pearl millet-Wheat	Wheat	Irrigated
Bihar	Vaishali, Samastipur, Purnea, Katihar, Begusarai, Patna and Jamui	North West, North East and South Bihar Alluvial Plains	Sandy loam to silty clay loam	1100-1400	Rice-Maize	Rice and Maize	Irrigated
West Bengal	Uttar Dinajpur and Nadia	Old and New Alluvial Zone	Sandy loam to silty clay loam	1300-1500	Rice-Maize	Maize	Irrigated

Treatments

Following four treatments were assessed in the on-farm experiments:
1) Ample NPK
2) Omission of N with full P and K
3) Omission of P with full N and K
4) Omission of K with full N and P

For rice, application rates of NPK were 125–175 kg N/ha, 50–80 kg P_2O_5/ha and 60–90 kg K_2O/ha based on estimated yield target of 5–8 t/ha. For wheat, N application rates were 150–180 kg/ha for 5–6 t/ha of yield target, while P and K rates were fixed at 90 kg P_2O_5 and 100 K_2O per hectare. Maize trials were concentrated in Bihar and West Bengal and ample NPK rates for maize were 150–180 kg N, 70–115 kg P_2O_5 and 120–160 kg K_2O per hectare for yield targets between 6–8 t/ha. Nutrients were applied in ample amounts to ensure no nutrient limitation except for the omitted nutrient. At maturity grain yields were determined from a 10 m^2 harvest area in each plot; combined after harvesting from four predetermined 2.5 m^2 spots within each plot. After sun-drying for three days in the field, the total biomass (grain + straw) was threshed with a plot thresher and grain yield was weighed, and adjusted to 13% moisture content for all the crops.

Yield Response to P and Profitability of P Application

Yield increase due to P fertiliser (P response) and P application economics were estimated using the following equations:

1) P response (kg/ha) = Grain yield in ample NPK plot (kg/ha) – Grain yield in P Omission plot (kg/ha)

2) Return on investment (ROI) on P fertiliser = Yield increase due to P fertiliser (kg/ha) x MSP of crop (Rs/kg) / Applied P_2O_5 (kg/ha) x cost of P_2O_5 (Rs/kg)

Economic Returns based on Actual P Responses, P Fertiliser Rates and P Fertiliser Prices

We calculated the ROI on P fertiliser (Eq 2 above) using actual P responses and fertiliser P rates applied for each location. We also used current minimum support prices (MSP) and P fertiliser prices at the time of the study.

Economic Returns based on Selected Levels of P Response, P Fertiliser Levels and P Fertiliser Prices

To better understand the economic return, we calculated ROI based on selected levels of P response, fertiliser P rates, and fertiliser P prices. P response levels used represented the range observed in the experiment. We used three different application rates (100, 80 and 60 kg of P_2O_5/ha) and four price levels of Di-ammonium phosphate (DAP)—Rs. 9350 (Rs. 16.22/kg of P_2O_5), Rs.10750 (Rs. 19.26/ kg of P_2O_5), Rs. 16700 (Rs. 32.20/ kg of P_2O_5), and Rs. 20,000 (Rs. 39.37/ kg of P_2O_5) per tonne.

Future Scenarios

Considering the escalating price of fertiliser in India, we assessed the ROI on P fertiliser for the 25th, 50th and 75th percentile of the actual P responses observed in different crops in this study. The aim of the exercise is to estimate ROI at actual and hypothetical costs of P_2O_5 and projected MSP of rice, wheat and maize.

The calculations were based on the following criteria:

- Five price levels of P_2O_5 between Rs. 19.26/kg P_2O_5 to Rs. 50.20/kg P_2O_5 that correspond to DAP prices between Rs. 10750 and Rs. 25000 per tonne.

- Three P response levels that correspond to 25th, 50th and 75th percentile of the actual responses observed in the experiments.

♦ Rice- P response levels used were 300, 500 and 800 kg/ha. We assumed that 300 kg/ha of P response justifies application of 30 kg P_2O_5/ha while P response of 500 and 800 kg/ha will require application at 40 and 60 kg P_2O_5/ha, respectively.

♦ Wheat- P response levels used were 600, 900, and 1300 kg/ha. Calculations are based on application rates of 40, 60 and 80 kg P_2O_5/ha at P response levels of 600, 900 and 1300 kg per hectare, respectively.

♦ Maize-P response levels used were 600, 900 and 1300 kg/ha. Calculations are based on application rate of 60 kg P_2O_5/ha at P response levels of 500 and 800 kg/ha, while 80 kg P_2O_5/ha was used for P response of 1100 kg/ha.

♦ Six MSP levels: 10–15 Rs/kg of rice, 11–16 Rs/kg of wheat, and 9–14 Rs/kg of maize.

RESULTS AND DISCUSSION

Yield Responses

The average yield of rice in the NPK treatment across 45 locations in the Indo- Gangetic Plains was 4701 kg/ha. P response in rice ranged from –194 to 2100 kg/ha with an average of 712 kg/ha across locations **(Figure 1)**, indicating the high variability of yield response across the study area. In general, yield with full NPK application and yield response in Punjab and Haryana were higher than those in eastern states of the study area. Higher P response in Trans-Gangetic Plain (Punjab and Haryana) as compared to remaining transect of IGP may be ascribed to better irrigation facilities, timely transplanting of rice and other efficient crop management practices. Whereas smaller plot size, lack of irrigation facilities and delayed transplanting in the eastern states are responsible for low yield and P response in rice (14).

Ample NPK treatment yield (n= 141) of wheat across the Trans and Upper Gangetic Plains ranged from 3111 to 6500 kg/ha, with an average of 5096 kg/ha. Trans and Upper Gangetic Plains regions have high attainable

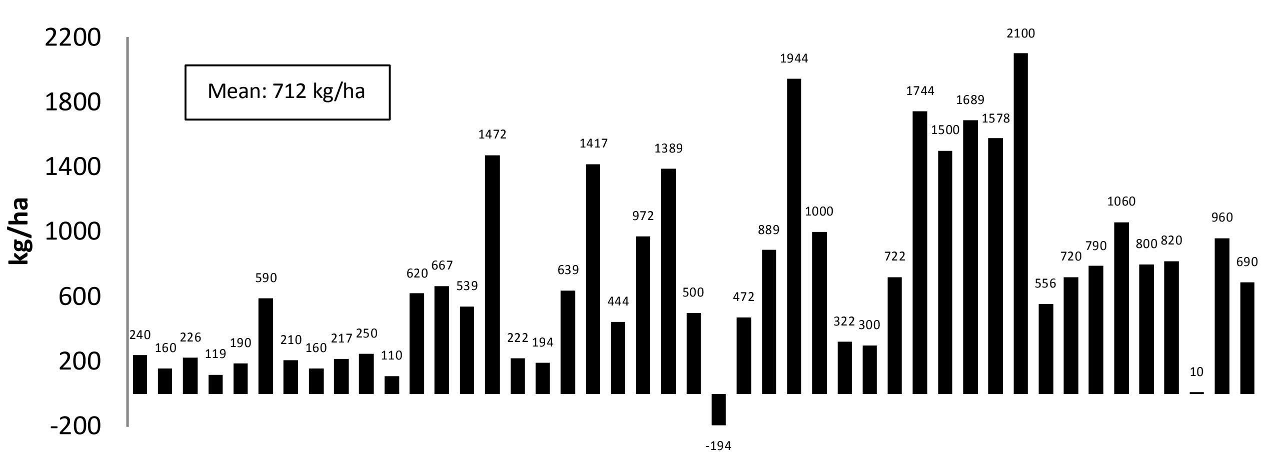

Figure 1 – P response in rice across 45 locations in the Indo-Gangetic Plains*

* P response = yield in fully-fertilised NPK plot – yield in P omission (–P) plot

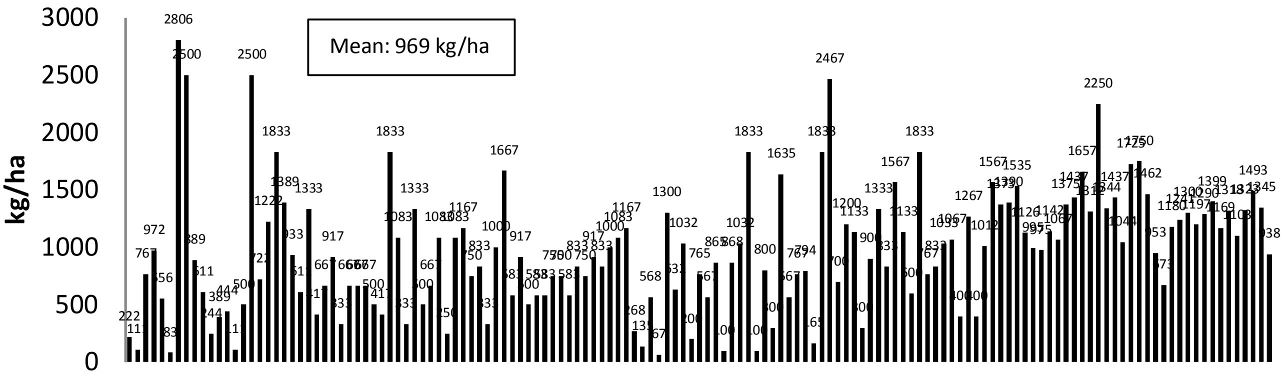

Figure 2 – P response in wheat across 141 locations in the Indo-Gangetic Plains*

* P response = yield in fully-fertilised NPK plot – yield in P omission (–P) plot

yield potentials and our experiments showed that yield target based nutrient application, combined with overall good crop management, can achieve yields across sites that are higher than average yields reported for individual states in the region (5). P response ranged from 67 to 2806 kg/ha with a mean of 969 kg/ha **(Figure 2)**. The average yield loss of 969 kg/ha in the P omission plots translates into an economic loss of Rs. 11337/ ha at the current MSP of wheat. It is interesting to note that among the three cereals studied, wheat had the highest P response. Greater yield response to P, in terms of percent increase in grain yield over no P treatment, in wheat compared with that in rice and maize is well corroborated with earlier findings of Dwivedi (3) and Tiwari (13).

Across 36 locations in Bihar and West Bengal, maize yield with full NPK ranged from 4020 to 9420 kg/ ha, with an average of 6343 kg/ ha. P omission plot yields across sites were highly variable (3910-8040 kg/ha) that corresponded to average P response of 853 kg/ha **(Figure 3)**. At the current MSP of maize of Rs. 8.80/kg grain, the yield loss due to no application of P in our experiments is equivalent to economic loss of Rs.792-15488/ha, with a mean of Rs. 7485/ha. In India, maize is grown in winter, spring and rainy seasons. Attainable yields of maize differ between seasons but highest yields are attained in winter. Consequently, the average P responses are higher in winter maize (1070 kg/ha) than in spring maize (513 kg/ha). These results are further substantiated with the findings of long-term experiments where NPK fertilisation at recommended rates improved partial factor productivity of all applied nutrient whereas skipping of any one nutrient had adverse effect on use efficiency of the other nutrients (14).

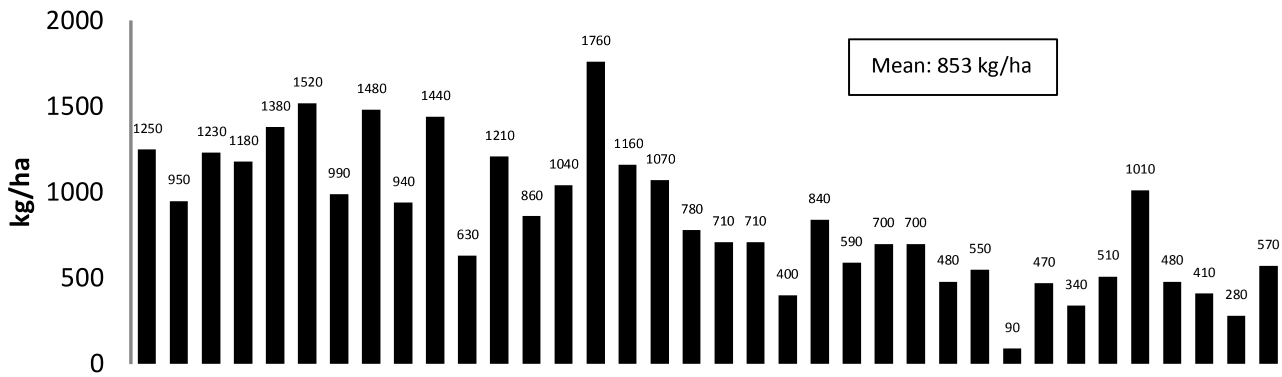

Figure 3 – P response in maize across 36 locations in Bihar and West Bengal*

* P response = yield in fully-fertilised NPK plot – yield in P omission (–P) plot

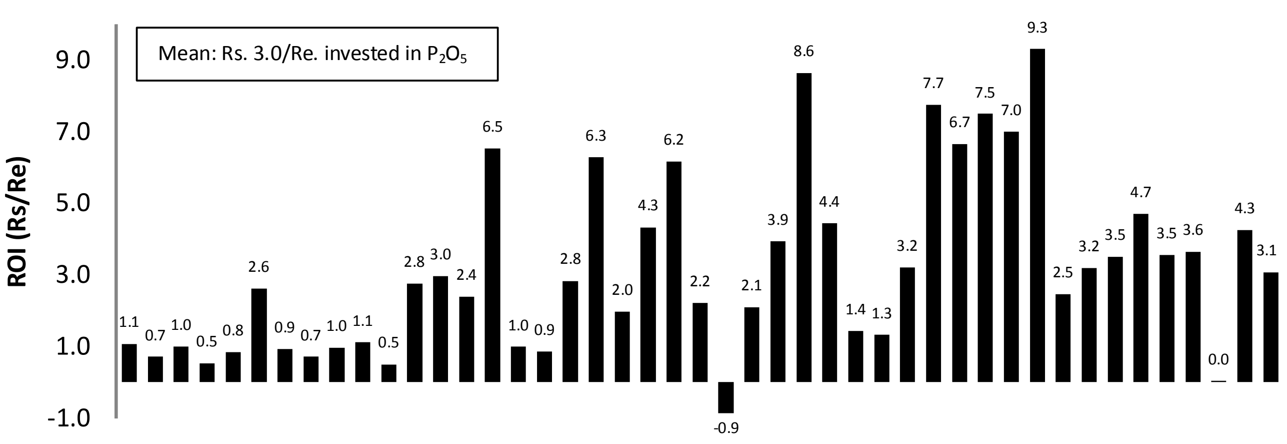

Figure 4 – Return on investment on P fertiliser in rice based on actual P rates and current

One way to cope with increasing fertiliser price is to increase crop yield by a certain yearly increment through better management. Several studies (6, 8, 13) have shown that there are wide gaps between farmers' plot yield and research station yields in the country. The researcher managed farmer participatory trials in this study showed that the ample NPK plot yields are much higher than the average yields of respective states. Location specific nutrient management strategies, with a focus on balanced and adequate application of all limiting nutrients, can help bridge the nutrient related yield gaps over a period of time that will increase farmer profitability and help meet the increasing food demand.

Economic Returns based on Actual P Responses, P Fertiliser Levels and P Fertiliser Prices

P fertiliser cost has increased considerably over the past four years. The increase in price of fertiliser makes it important that the resource is used in a manner that maintains the profitability of P application in rice, wheat and maize where the minimum support prices are low.

Economic calculations showed that ROI on P fertiliser for rice ranged from -0.9 to 4.0 Rs/Re **(Figure 4)**. Average ROI across locations was 3.0 Rs/Re. ROI was ≤1 Rs/Re in twelve locations at an average ample application rate of 70 kg P_2O_5/ha. The ample rates used in the omission plot experiments are kept higher than the crop's required amount to ensure no limitations for nutrients that might limit estimation of true response of the omitted nutrient.

Return on investment was calculated based on minimum support price of rice (Rs 10/kg) and price of phosphate fertiliser (Rs. 32.20/kg of P_2O_5).

ROI on P fertiliser in the wheat experiments ranged from 0.3-11.0 Rs/Re with a mean of 4.0 Rs/Re **(Figure 5)**. ROI on P fertiliser was

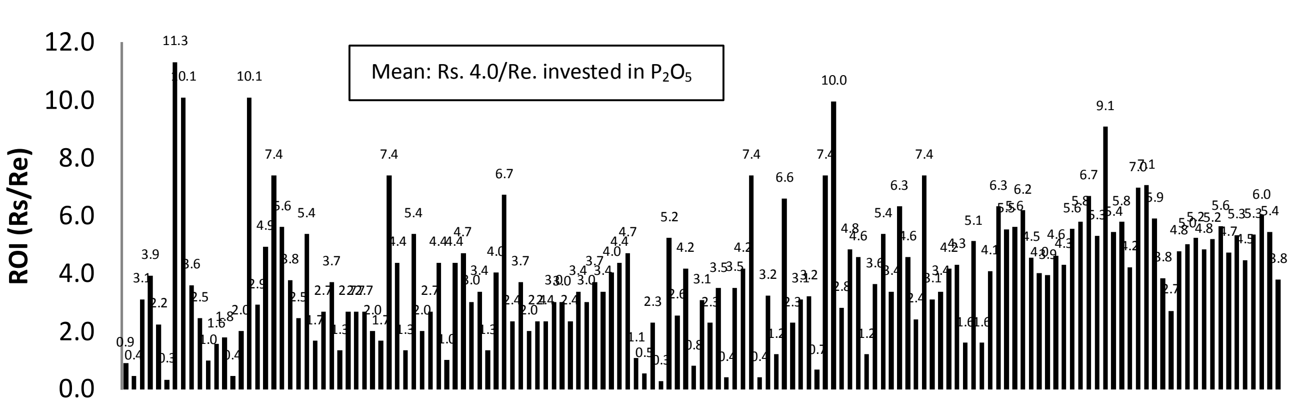

Figure 5 – Return on investment on P fertiliser in wheat based on actual P rates and current fertiliser costs and MSP

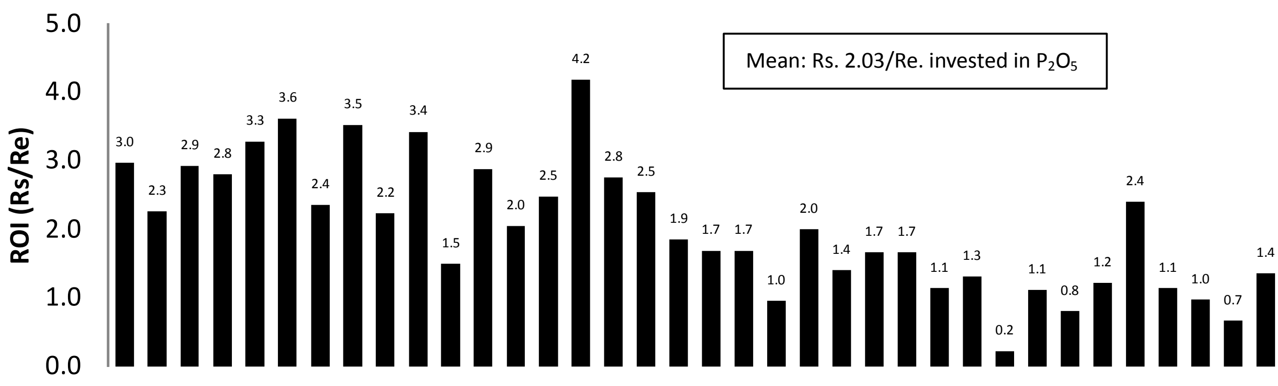

Figure 6 – Return of investment (ROI) on P fertiliser in maize based on actual P rates and current fertiliser costs and MSP

lower than 2.0 only in 24 out of the 141 sites at an ample application rate of 90 kg P_2O_5/ha. Averaged across locations, the mean ROI values (Rs 4.0/ Re invested on P_2O_5) was highest in wheat as compared to rice and maize.

Return on investment was calculated based on minimum support price of wheat (Rs 11.7/kg) and price of P fertiliser (Rs. 32.2/kg of P_2O_5).

At an ample application rate of 115 kg P_2O_5/ha, ROI on P fertiliser in maize was 0.2 – 4.2 Rs/Re and the average return across all sites was 2.03 Rs/Re **(Figure 6).** The return on investment on P fertiliser was below 2.0 Rs/Re in 50% of the locations as the MSP of maize is lowest among the three cereals, and the omission plot experiments used a high rate of P.

The economic returns due to P application in the three cereals **(Figures 5, 6 and 7)** were based on ample rates of P that were applied to ensure no hidden limitation of nutrients. Such high nutrient rates usually give a wrong estimate of economic return. The following section provides a better understanding of ROI based on more appropriate P rates for the range of P responses observed in this study.

Economic Returns based on Selected Levels of P Response, P Fertiliser Levels and P Fertiliser Prices

Table 2 shows ROI on P fertiliser in rice at four levels of P response (500, 1000, 1500 and 2000 kg/ha),

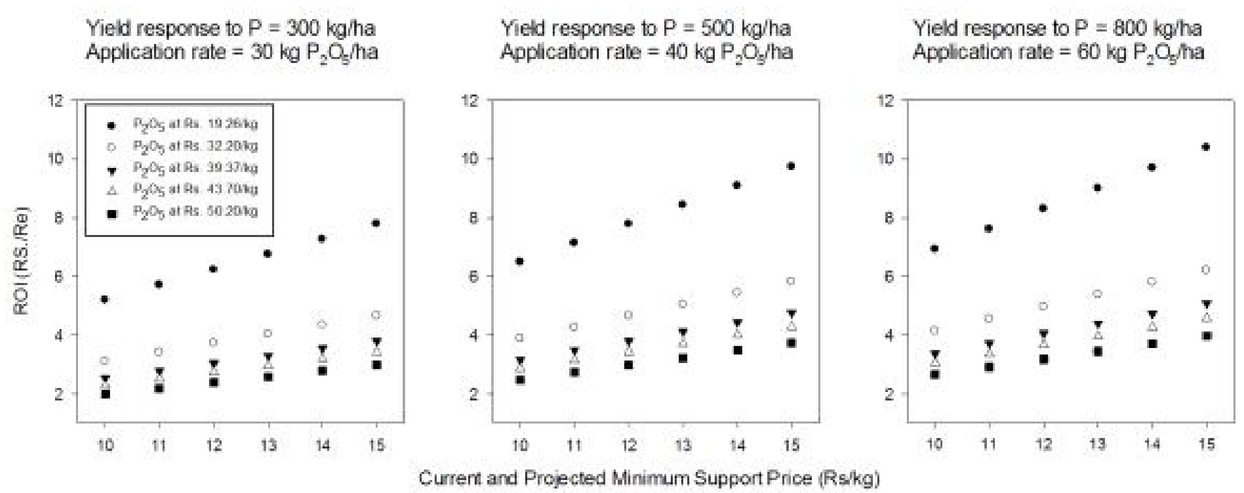

Figure 7 – Return on investment (ROI) on P fertiliser at different P response levels and projected cost of P fertiliser and minimum support price of rice

Table 2 – Return on investment (ROI) in P fertiliser in rice at different crop response levels, cost of DAP and application rates

Yield response to P (kg/ha) →	500	1000	1500	2000
Cost of DAP (Rs/ tonne) ↓				
	At 100 kg P_2O_5/ha application rate			
9350	3.08	6.17	9.25	12.33
10750	2.60	5.19	7.79	10.38
16700	1.55	3.11	4.66	6.21
20000	1.27	2.54	3.81	5.08
	At 80 kg P_2O_5/ha application rate			
9350	3.85	7.71	11.56	15.42
10750	3.24	6.49	9.73	12.98
16700	1.94	3.88	5.82	7.77
20000	1.59	3.18	4.76	6.35
	At 60 kg P_2O_5/ha application rate			
9350	5.14	10.28	15.42	20.55
10750	4.33	8.65	12.98	17.31
16700	2.59	5.18	7.77	10.35
20000	2.12	4.23	6.35	8.47

Calculated based on minimum support price of rice (Rs 10/kg of grain)

Economic return among the three cereals was lowest for maize as the MSP of maize is the lowest among the three **(Table 4)**. However, economic return is fairly high at all application levels in areas where P response is $\geq$1000. The results from the current on-farm trial showed that more than 75% of the experimental sites had $\geq$ 500 kg/ha of P response and would give reasonably high ROI on P fertiliser.

Future Scenarios

Considering the escalating price of fertiliser in India, the return on investment (Rs returned/Re invested on P_2O_5) for the 25th, 50th and 75th percentile of the actual P responses observed in different crops in the present experiments was assessed. The aim of the exercise is to estimate return from investment on phosphatic fertiliser, at actual and hypothetical costs of and at three P application rates (100, 80 and 60 kg of P_2O_5/ ha). Results revealed that P application is economical except in situations where P cost is high (Rs. 32.20/ kg and Rs. 39.37/ kg of P_2O_5), P response is low ($\leq$ 500 kg/ha) and P fertiliser is applied at 80-100 kg/ha (**Table 2**, shaded boxes). P application is economical even at the higher prices and at low response levels when phosphorus is applied at a rate of 60 kg/P_2O_5 per hectare.

In general, P application in wheat is more economical than in rice **(Table 3)**. Comparatively higher MSP of wheat and a larger range of P response provide more opportunity of higher economic return to the farmers. P application tends to become uneconomic when P cost is high (Rs. 32.20/ kg and Rs. 39.37/ kg of P_2O_5), P response is low ($\leq$ 500 kg/ha) and application rate is 80-100 kg P_2O_5/ha. Except in one scenario, P application is highly economical throughout the response range and at all prices when applied at a rate of 60 and 80 kg P_2O_5/ha **(Table 3)**.

Table 3 – Return of investment (ROI) on P fertiliser in wheat at different crop response levels, cost of DAP and application rates

Yield response to → P (kg/ha)	500	1000	1500	2000	2500
Cost of DAP (Rs/ tonne) ↓					
		At 100 kg P_2O_5/ha application rate			
9350	3.61	7.21	10.82	14.43	18.04
10750	3.04	6.07	9.11	12.15	15.19
16700	1.82	3.63	5.45	7.27	9.09
20000	1.49	2.97	4.46	5.94	7.43
		At 80 kg P_2O_5/ha application rate			
9350	4.51	9.02	13.53	18.04	22.55
10750	3.80	7.59	11.39	15.19	18.98
16700	2.27	4.54	6.81	9.09	11.36
20000	1.86	3.71	5.57	7.43	9.29
		At 60 kg P_2O_5/ha application rate			
9350	6.01	12.02	18.04	24.05	30.06
10750	5.06	10.12	15.19	20.25	25.31
16700	3.03	6.06	9.09	12.11	15.14
20000	2.48	4.95	7.43	9.91	12.38

Calculated based on minimum support price of wheat (Rs 11.7/kg of grain)

Table 4 – INR return per INR invested on phosphate in maize at different crop response levels, cost of DAP and application rates

Yield response to P (kg/ha) ⟶	500	1000	1500	2000
Cost of DAP (Rs/ tonne) ↓				
	At 100 kg P_2O_5/ha application rate			
9350	2.71	5.43	8.14	10.85
10750	2.28	4.57	6.85	9.14
16700	1.37	2.73	4.10	5.47
20000	1.12	2.24	3.35	4.47
	At 80 kg P_2O_5/ha application rate			
9350	3.39	6.78	10.17	13.57
10750	2.86	5.71	8.57	11.42
16700	1.71	3.42	5.12	6.83
20000	1.40	2.79	4.19	5.59
	At 60 kg P_2O_5/ha application rate			
9350	4.52	9.04	13.57	18.09
10750	3.81	7.61	11.42	15.23
16700	2.28	4.56	6.83	9.11
20000	1.86	3.73	5.59	7.45

Calculated based on minimum support price of maize (Rs 8.80/kg of grain)

P_2O_5, and projected minimum support price of rice, wheat and maize.

Rice

Figure 7 shows that P application, in general, is economically profitable even in areas where P response is low (300 kg/ha). At an application rate of 30 kg P_2O_5/ha, the ROI at the highest price of phosphate fertiliser (Rs. 50.20/kg P_2O_5) and the lowest MSP (Rs. 10/kg rice) was 2.0 Rs/Re suggesting profitable return on P application. At higher response levels, 500 and 800 kg/ha, the ROI increased to 2.5 and 2.7 at highest price of P fertiliser and lowest MSP **(Figure 7)**. The ROIs were 2.5, 3.3 and 3.4 Rs/Re at P response levels of 300, 500 and 800 kg/ha at current cost of P fertiliser and current MSP. This suggests that using P response as a guiding factor to determine application rates will help farmers achieve reasonable return on investment. **Figure 7** also shows how farmers' returns could be increased through reasonable increase in MSP of rice under increasing fertiliser price scenarios.

Wheat

Economic calculations based on projected cost of P fertiliser and MSP showed that there is a sharp decline in ROI as the P fertiliser price increases from Rs. 19.26/kg to a projected price of Rs. 50.20/kg of P_2O_5 **(Figure 8)**. However, **Figure 8** also suggests that ROI at the current MSP and the projected maximum price of P fertiliser would be 3.3 Rs/Re, a return ratio of 1:3 even at the low P response areas. At high P response areas (≈ 1300 kg/ha), the ROI at highest

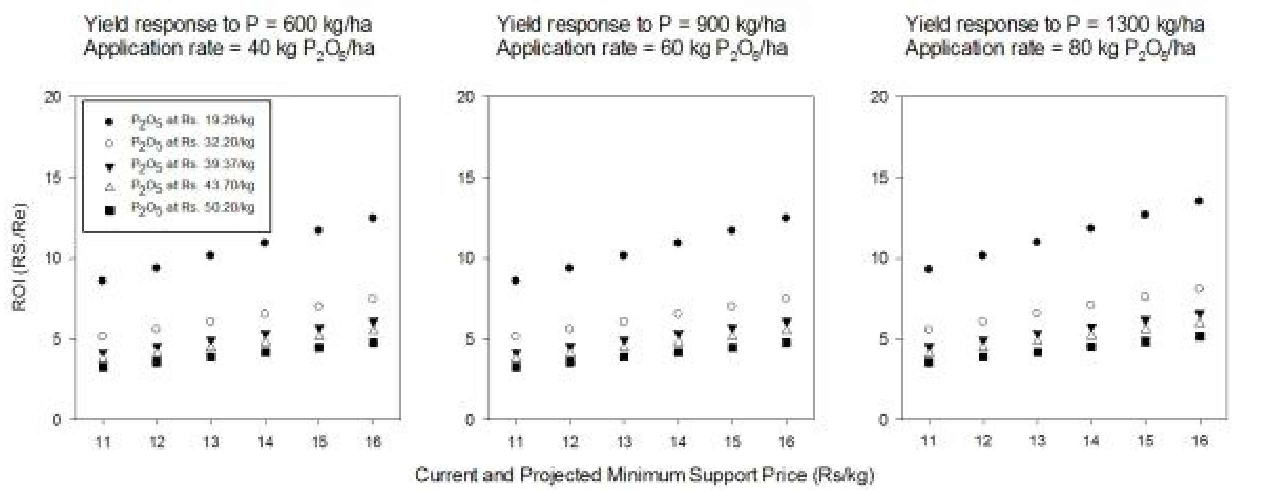

Figure 8 – Return on investment (ROI) on P fertiliser at different P response levels and projected cost of P fertiliser and minimum support price of wheat

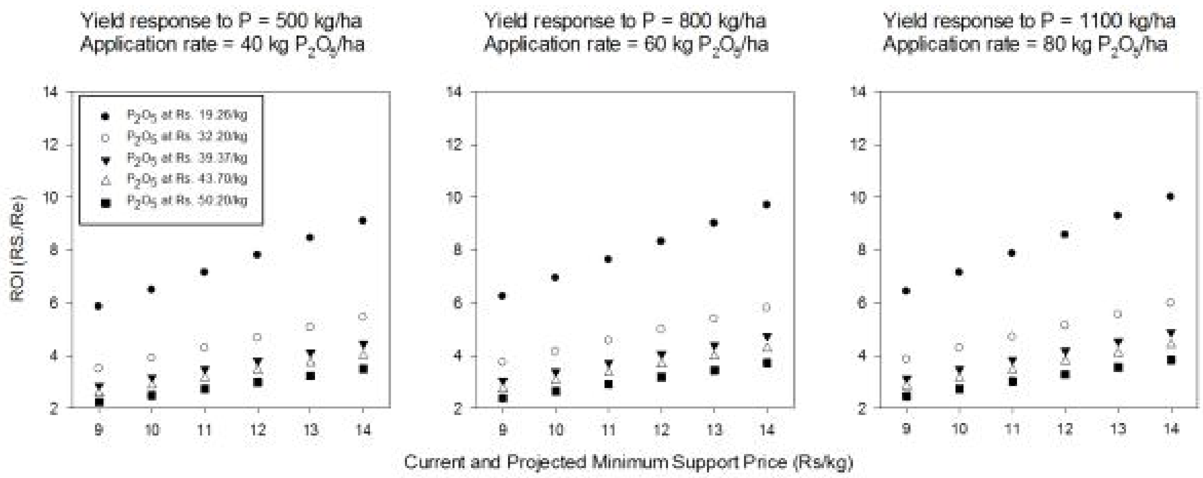

Figure 9 – Return on rupees invested on phosphate at varying P response levels, cost of P2O5 and minimum support price of maize

projected fertiliser P price would be 3.6 Rs/Re at the current MSP of wheat, making it a profitable option for the farmers.

Maize

Maize MSP is lowest among the cereals. However, ROI at the current MSP and highest cost of P fertiliser were $\geq$ 2.0 in all the three P response levels **(Figure 9)** suggesting that P application at the given rates would be economical to the farmers.

CONCLUSION

The on-farm P response study in rice, wheat and maize, spread across the Indo-Gangetic Plains, highlights that

1) P response is highly variable and is influenced by soil characteristics and growing environment of the crop. P application rate, therefore, must be based on expected response of a particular location.

2) No application of P fertiliser in randomly selected farmers' fields showed that average yield loss due to P-omission was 712 kg/ha in rice, 969 kg/ha in wheat, and 853 kg/ha in maize.

3) Economic assessment based on application rates, nutrient response, cost of phosphate and minimum support price of the cereals showed return on investment (Rs/Re) of 2 in all scenarios.

This study showed that P fertiliser application rates that are guided by expected P responses will allow greater economic returns from cereal farming under the increasing fertiliser price scenario. This will ensure sufficient P availability through external P application to support high production systems in P deficient areas. Areas with higher P fertility would respond less economically to P application and would suggest lesser application rates to prevent unnecessary loss of unutilized nutrients to the environment. However, one of the shortcomings of nutrient application based on yield response alone is that it does not account for nutrient removal by crops where response is low or negligible. In such scenario, nutrient removal by the crop would not be replenished by external application, which could lead to nutrient mining and decline in soil fertility. One way to counter that would be to apply a maintenance dose that replenishes part of the nutrient exported out of the field with harvested crop part (grain and straw). This will ensure that soil fertility levels that can support intensive production systems are maintained.

REFERENCES

1. Barber, S. A., Walker, J. M. and Vasey, E. H. *J. Agric. Food Chem.* 11, 204-207 (1963).

2. Batjes, N. H. A world data set of derived soil properties by FAO-UNESCO soil unit for global modeling. Soil Use Manage. 13, 9-16 (1997).

3. Dwivedi, B. S. Annual report. PDCSR, Modipuram, India, pp. 10-12 (1994).

4. Eswaran, H., Reich, P. and Beinroth, F. *Brazilian Soil Sci. Soc.*, Sao Paulo, Brazil. (1997).

5. Fertiliser Statistics. The Fertiliser Association of India, New Delhi, India (2010-11).

6. Ladha, J. K., Dawe, D., Pathak, H., Padre, A. T., Yadav, R. L. and Singh, B. *Field Crops Res.*, 81: 159-180 (2003).

7. Motsara, M. R. *Fert. News*, 47 (8), 15-21 (2002).

8. Pathak, H., Patra, A. K., Kalra, N. *Indian J. Fert.* 1 (4), pp. 27-28 & 31-37 (2005).

9. Raghothama, K. G. Phosphorus and Plant Nutrition. In: Phosphorus: Agriculture and the Environment. Agronomy Monograph No. 46, ASA-CSSA-SSSA, Madison, Wisconsin, USA. (2005).

10. Sanchez, P. A., Shephard, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, A. N., Mokwunye, A. U., Kwesiga, F. R., Ndiritu, C. G. and Woomer, P. L. Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capital. In R. J. Buresh et al.(Eds), Replenishing Soil Fertility in Africa. SSSA, Madison, WI. (1997).

11. Sharpley, A. N., McDowell, R. W. and Kleinman, P. J. A. *Plant Soil*, 237, 287-307 (2001).

12. Swarup, A., Wanjari, R. H. Three Decades of All India Coordinated Research Project on Long-term Fertiliser Experiments to Study Changes in Soil Quality, Crop Productivity and Sustainability. IISS, Bhopal, India (2000).

13. Tiwari, K. N. *Indian J. Fert.* (9), 73-80, 83-90 & 93-98 (2006).

14. Yadav, R. L. *Expl. Agric.* 37, 99-113 (2000). ■