Importance of Phosphorus Management in Maize-Wheat Cropping Systems

By Rakesh Kumar, S. Karmakar, A.K. Sarkar, Sudarshan Dutta, Kaushik Majumdar, T. Satyanarayana, and Adrian M. Johnston

Omission of phosphate fertilizer reduced cropping system productivity, showing the importance of balanced P application in the relatively low fertility red and lateritic soils of Jharkhand.

Yields within the state of Jharkhand's maize-wheat cropping system are under performing at 1.8 and 1.9 t/ha, respectively. These yields are much lower than the national averages of 2.6 t/ha (maize) and 3.1 t/ha (wheat) (FAI, 2014). This region of eastern India has large tracts of red and lateritic soils that have coarse texture, low organic matter content, low pH, and generally low availability of N, P, K, secondary, and micronutrients.

Increased cereal crop production can be addressed in these soils through the use of high-yielding varieties and improved nutrient management. It is realistic to expect two to three-fold increases in crop yields with the adoption of these practices. The approach of this research was to estimate inherent soil nutrient supply through the nutrient omission plot technique, which was followed by adequate and balanced application of all yield-limiting nutrients, based on attainable yield targets.

As part of the IPNI Global Maize Initiative >http://research.ipni.net/article/EXP-3006<, field experiments were conducted for three consecutive years (2010-11 to 2012-13) at the Birsa Agricultural University Farm in Ranchi, Jharkhand to assess the effect of nutrient use and phosphate omission on crop yields, nutrient uptake, soil health, and the economics of the maize-wheat cropping system. The experiments used hybrid maize (var. Pioneer 30V 92 planted within a 70 x 18 cm geometry), which was grown during the rainy season as a rain-fed crop (June to October). The following wheat crop (var. DBW 17, 25 cm row-to-row spacing) was grown in winter as an irrigated crop.

The experimental area falls within the sub-tropical Eastern Plateau and Hill region. The soil was sandy loam in texture with pH 5.2, 4.9 g O.C./kg, low available N, P and K (272 kg N/ha, 32 kg P_2O_5/ha, 139 kg K_2O/ha) determined by Subbiah and Asija (1956), Bray and Kurtz No. 1 (1956), and Jackson (1967) methods, respectively. The study's four treatments included: 1) ample NPK (250-120-110 kg N-P_2O_5-K_2O/ha for maize and 150-110-100 kg N-P_2O_5-K_2O/ha for wheat), 2) P omission from ample NPK, 3) SSNM (200-90-100 kg N-P_2O_5-K_2O/ha for maize and 120-70-60 kg N-P_2O_5-K_2O/ha for wheat), and 4) Farmers' Fertilization Practice (FFP – 2.5 t FYM/ha + 20 kg N/ha). All treatments were laid out in a randomized block design with four replications. Rates within the ample NPK treatment were chosen to avoid any nutrient limitation, while SSNM rates were based on published nutrient uptake values for maize, and nutrient use efficiencies for this soil type (Setiyono et al., 2010; IPNI personal communication). Nutrient application under FFP for maize and wheat were based on a farmers' participatory survey conducted with 10 maize-wheat growing farmers from the study region. The limiting secondary and micronutrients were applied to all treatments.

Abbreviations and notes: N = nitrogen, P = phosphorus; K = potassium; O.C. = organic carbon; SSNM = site-specific nutrient management. 1 US$ = 67 Indian Rupees (Rs.). IPNI Project IND-GM22.

IPNI Image/S. Dutta

IPNI Image/K. Majumdar

A visit to the maize-wheat experiment site at Birsa Agricultural University Farm in Ranchi, Jharkhand. Dr. Majumdar (L), Dr. Kumar (C), and Dr. Dutta (R) shown in top photo.

For calculation of the system yield, grain yield of wheat was converted to maize equivalent yield (MEqY) by using the following equation:

$$MEqY = \frac{[\text{wheat yield (kg/ha) x selling price of wheat (Rs/kg)}]}{\text{selling price of maize (Rs/kg)}} + \text{maize yield (kg/ha)}$$

Temporal variability of P response during 2009-13 was calculated as:

$$\text{P response (kg/ha)} = \text{grain yield in ample NPK (kg/ha)} - \text{grain yield in P omission (kg/ha)}$$

The economic benefit was calculated by the Return on Investment (ROI) for P fertilizer use calculated as:

$$ROI = \frac{\text{yield increase due to P fertilizer (kg/ha) x minimum support price of crop (Rs/kg)}}{\text{applied } P_2O_5 \text{ (kg/ha) x cost of } P_2O_5 \text{ (Rs/kg)}}$$

Composite surface soil samples (0 to 15 cm) were collected after two crop cycles for available N, P and K analysis. Agronomic efficiency (AE) of P was calculated as described by Cassman et al. (1998).

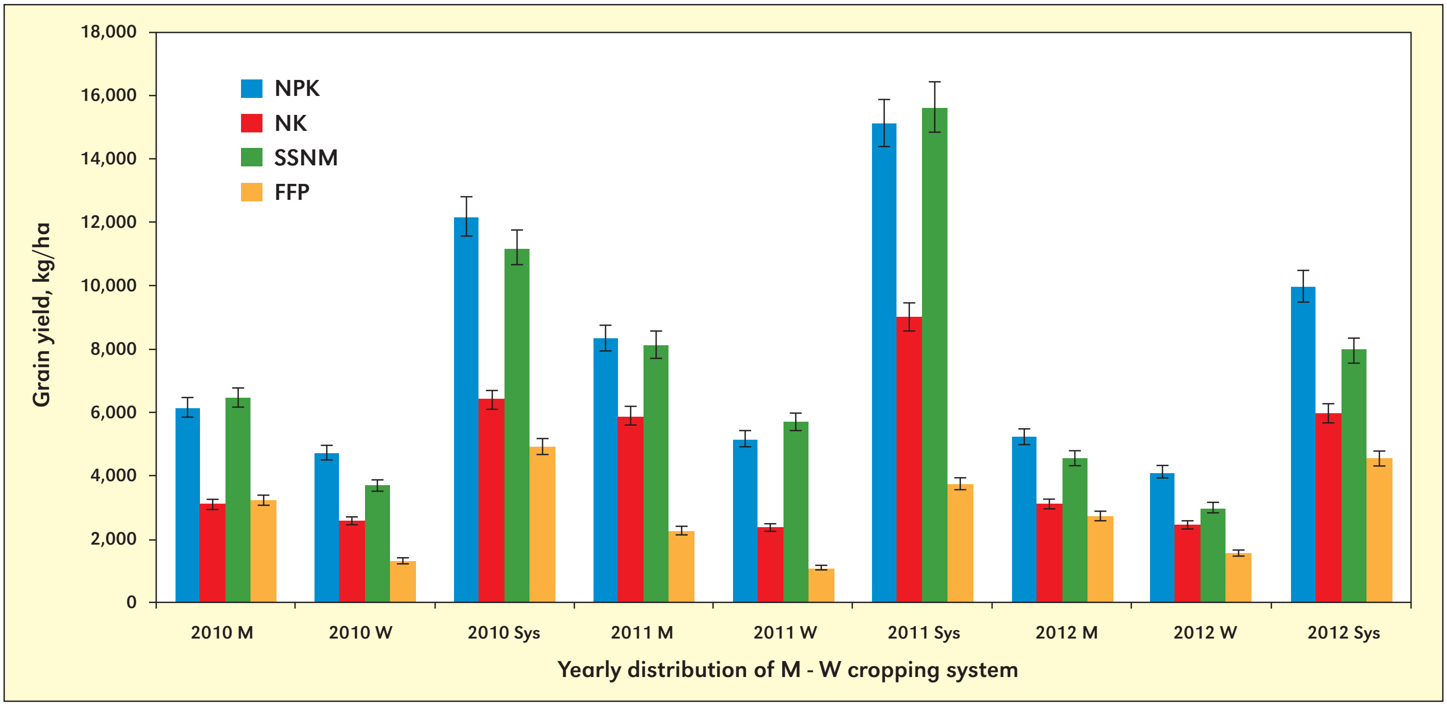

Figure 1. Grain yield of maize (M) and wheat (W) in maize-wheat sequence (Sys). SSNM and FFP = Site-Specific Nutrient Management and Farmers' Fertilization Practice, respectively. Error bars = Standard errors.

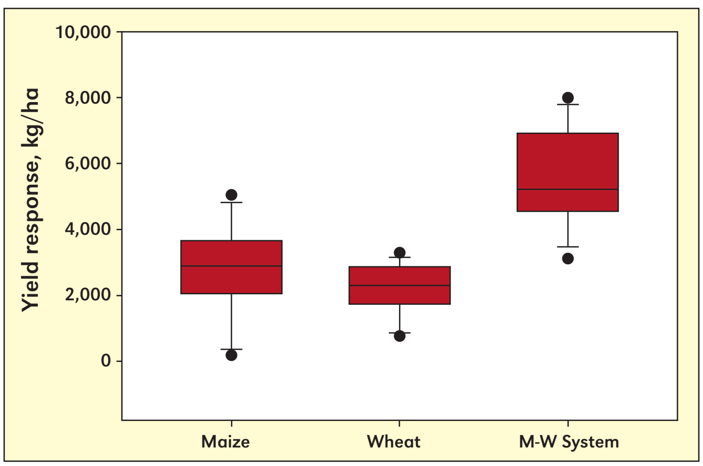

Figure 2. Average grain yield response of maize (M), wheat (W) and the system to applied phosphorus across three years of study (n = 36). Boxes represent data within the first and third quartiles (interquartile range). Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

Crop Yield and Nutrient Uptake

Application of P fertilizer enhanced both maize and wheat yields, and overall system productivity (MEqY). Maize grain yields were > 5 t/ha for both NPK and the SSNM treatments and were significantly ($p \leq 0.05$) higher compared to P omission as well as FFP plots (**Figure 1**). The same trend was observed for wheat yield where the NPK and SSNM plots averaged > 4 t/ha and were significantly ($p \leq 0.05$) higher than the 0 P and FFP treatments.

In 2010, the average grain yield in NPK maize and wheat plots was 6.2 t/ha and 4.7 t/ha, respectively; while the system productivity was 12.2 t/ha. In contrast, the P omission plot had a maize yield of only 3.1 t/ha and wheat productivity was 2.6 t/ha. In the SSNM plot, the maize productivity was 6.5 t/ha and wheat productivity was 3.7 t/ha with a system productivity of 11.2 t/ha. The FFP plot productivity for maize, wheat, and the system were 3.2, 1.3, and 4.9 t/ha, respectively.

In 2011, maize and wheat productivity under NPK increased up to 8.4 t/ha and 5.2 t/ha, respectively, while the system productivity went up to 15.1 t/ha. These productivities were significantly ($p \leq 0.05$) higher than P omission plots (6.6, 2.4 and 9.8 t/ha, respectively) and FFP (2.2, 2.1 and 5.0 t/ha, respectively) and were at par with the SSNM treatment (8.1, 5.7 and 15.6 t/ha, respectively). Higher maize production in 2011 could be attributed to the better rainfall pattern during the monsoon *kharif* 2011 and more favorable winter temperature during the following *rabi* season.

In 2012, grain yields were similar to those in 2010 where NPK yields for maize, wheat, and the system were 6.6, 4.1 and 11.4 t/ha and were significantly ($p \leq 0.05$) higher than P omission (3.1, 2.5 and 6.0 t/ha) and FFP (2.8, 1.6 and 4.6 t/ha) treatments. The SSNM yields (3.6, 3.8 and 8.0 t/ha) were also significantly ($p \leq 0.05$) higher than P omission and FFP plots. It was noted that the average maize and wheat yields of the 0 P treatment were significantly ($p \leq 0.05$) higher than the FFP from the 2010 wheat season onwards. Thus, although the P omission plot did not receive P fertilizer, its overall fertilization schedule appeared comparatively better than FFP as it did receive better N and K input (**Figure 1**).

The response study reported that the mean P response for maize was 2.8 t/ha, 2.2 t/ha for wheat and 5.5 t/ha for the MW system (**Figure 2**). In the case of maize, the response was highest in 2012 (3.5 t/ha) followed by that of 2010 (3.1 t/ha) and then 2011 (1.8 t/ha). Phosphorus deficiency is well reported on acidic soils because of the rapid reversion of soluble P into insoluble forms through reactions with iron and aluminum oxides. Therefore, P fertilizer has a very important role within the maize-wheat system, especially when compared with FFP.

Nutrient Use Efficiency

Nutrient use efficiency (NUE) provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system. Agronomic Efficiency (AE) and Partial Factor productivity (PFP) are useful measures of NUE (Cassman et al., 1998). The AE values for maize and wheat varied (example equation for AE (P_2O_5) = (Yield in NPK plot – Yield in P omission plot) / P_2O_5 applied x 100) although there was no crop-wise pattern. Temporal variation also was observed in AE values in the present study; there was a decreasing trend in the AE value for maize from 2010 to 2012. On the other hand, AE of wheat increased in 2011 from 2010, but again decreased in 2012. Similarly the AE of the maize-wheat system increased in 2011 from 2010, but decreased in 2012 (**Table 1**). This could be attributed to the higher yield of both maize and wheat in the year of 2011. The PFP is being calculated by dividing the grain yield with the amount of nutrient applied; therefore, it is an indication of production per unit of nutrient applied. PFP can be increased with the increase in the amount, uptake and utilization of indigenous nutrients. PFP can also improve by increasing the efficiency with which applied nutrients are taken up by the crop and utilized to produce grain. The PFP value for P_2O_5 was significantly higher in the SSNM treatments compared to NPK (**Table 1**), and it is expected as SSNM yield was at par with NPK with lower rates of P_2O_5.

Table 1. Temporal variation of yield attributes across different treatments.

		----- 2010 -----		----- 2011 -----		----- 2012 -----	
		Maize	Wheat	Maize	Wheat	Maize	Wheat
Agronomic efficiency, kg grain/kg P	NPK	25.5	17.8	20.7	23.3	17.6	13.8
Partial factor productivity, kg grain yield/kg applied nutrient	NPK	51.4 a*	43.1 a	69.7 a	47.0 a	43.7 a	37.5 a
	SSNM	72.0 b	61.9 b	90.4 b	95.5 b	50.8 b	49.9 b

*Different letters within columns depict statistically significant ($p \leq 0.05$) differences.

Table 2. Prices of fertilizer, and minimum support prices for maize and wheat during the study.

Prices, Rs./kg	2010	2011	2012
Single superphosphate (50 kg bag)	197.00	197.00	360.00
P_2O_5	24.62	24.62	45.00
Maize	8.80	9.80	11.75
Wheat	11.70	12.85	13.50

Source: Primary Agriculture Cooperative Society, Government of Jharkhand; http://dfpd.nic.in/minimum-support-prices.htm

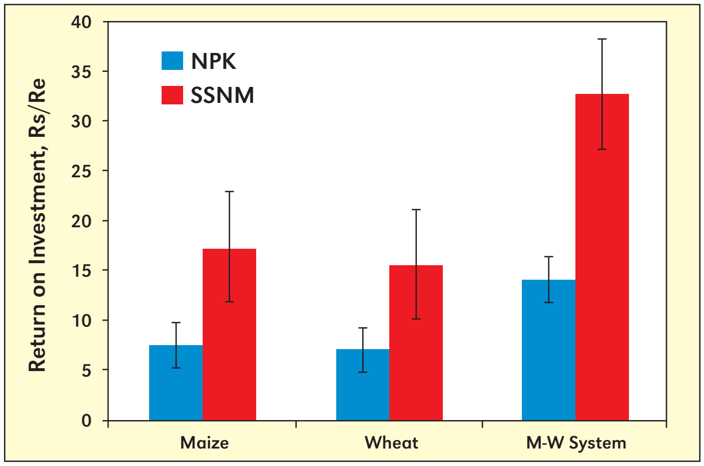

Figure 3. Return on investment values (Rupees invested/Rupees expended) for NPK and Site-Specific Nutrient Management treatments. The prices considered for calculations are given in Table 2. Error bars = Standard errors.

Economics

Return on investment (ROI) was calculated based on the varying minimum support price of maize and wheat and the unit price of P_2O_5 determined based on the unit price of single superphosphate (SSP) fertilizer (**Table 2**). Economic analysis of the nutrient management practices was determined through ROI that highlights the increase in profitability per unit investment in a particular nutrient. The study revealed that the ROI was higher with SSNM compared to NPK plots (**Figure 3**). A lower ROI value associated with the NPK treatment, ranged from 5 to 9 Rs/Re (Rupees invested/Rupees expended) for maize, 4 to 9 Rs/Re for wheat, and from 12 to 17 Rs/Re from the maize-wheat system. These results were significantly less than the SSNM treatments where ROI ranged from 12 to 24 Rs/Re for maize, 9 to 23 Rs/Re for wheat and 18 to 47 Rs/Re for system. Higher ROI in SSNM compared to NPK can be attributed to higher input cost associated with additional nutrients prescribed by the omission plot protocol (applications made to avoid any deficiency). The system ROI was also increased in the maize-wheat cropping system, indicating that production and profitability could be increased in maize-wheat systems in Jharkhand with balanced nutrient management practices, especially when special emphasize is given to P nutrient management.

Summary

This study shows that application of P fertilizer increases the maize, wheat, as well as maize–wheat system yield significantly over FFP and P omitted plots, accruing higher economic benefit in this process. BC

Dr. Kumar (E-mail: rkssacbau@rediffmail.com) is Professor, Department of Soil Science and Agriculture Chemistry; Dr. Karmakar is Chief Scientist, Department of Agronomy; Dr. Sarkar is Former Dean, Faculty of Agriculture—all with Birsa Agricultural University, Kanke, Ranchi, India. Drs. Dutta, Majumdar, Satyanarayana are with IPNI South Asia Program; Dr. Johnston is IPNI Vice President, and Asia, Africa and Mid East Coordinator.

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