Phosphorus Response and Benefits of Phosphorus Fertilizer Use in Maize-Wheat Cropping System of Northern Karnataka

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A study conducted for six years in the maize-wheat cropping system (MWCS) showed a declining response to P application while maintaining a steady P uptake owing to a constant supply of readily available P in the deep black soils of Northern Karnataka.

A site-specific P management strategy developed based on P response, the dynamics of P uptake, and the ROI of P use can help improve the yield and profitability of MWCS.

Staff and Cooperators of IPNI visiting the long-term experiments on MWCS at UAS, Dharwad, Karnataka.

The maize-wheat cropping system (MWCS) is the third most important cropping system after rice-wheat and rice-rice, and contributes about 3% to the national food basket in India. It is one of the emerging agricultural production systems in India, ranks first among different maize-based cropping systems, and occupies 1.8 million (M) ha area mainly concentrated in the rain-fed ecologies (http://agridaksh.iasri.res.in). Due to the wider adaptability and compatibility of maize under diverse soil and climatic conditions, maize-based cropping systems in general, and MWCS in particular, is considered as an alternative option for diversification of rice-wheat or rice-rice production systems of the country (Timsina et al. 2010).

The annual maize production in India is about 21.7 M t with an annual growth rate of 3 to 4 % (Jat et al., 2012). India's average maize yield at 2.5 t/ha is less than half of the global average of 5.5 t/ha, and there is a large potential for improving the productivity of maize in the country. India produces about 93.5 M t of wheat annually (FAI Statistics, 2014). India is the second largest producer as well as the third largest consumer of wheat in the World, indicating a growing demand for wheat. In Karnataka, maize is grown on about 1.3 M ha, producing about 3.5 M t grain at an average productivity of 2.6 t/ha; while 0.18 M t of wheat is grown on about 0.23 M ha of cultivated area (Fertiliser Statistics, 2014). The overall productivity of MWCS in northern Karnataka is low due to unbalanced and inadequate application of nutrients; farmers invariably apply nutrients through complex fertilizer sources where the application is not in accordance with the crop nutrient requirement. In fact the cheaper access of fertilizer N in India means some farmers do not even consider applying P and K fertilizers in the entire nutrient management program.

Phosphorus nutrition is critical for the early growth and development of maize, affecting root morphological and physiological characteristics that are important for nutrient uptake. It plays a vital role in every plant process such as photosynthesis, energy storage and transfer; helps in stimulating the growth and development of the root system; gives the plant a rapid and vigorous start leading to better tillering in wheat, encouraging earlier maturity and seed formation. Considering the benefits of P fertilizer use in MWCS, and looking at the inadequate P fertilizer use scenario in Northern Karnataka, a study was undertaken to determine the response to P fertilizer and document the agronomic and economic benefits of P fertilizer use in MWCS.

The experiment was set up at the main agricultural research station of the University of Agricultural Sciences in Dharwad, Karnataka, as a part of the IPNI Global Maize Initiative. The site is located in the southern plateau and hills region at 15° 28' N latitude and 75° 1' E longitude. The area falls under the hot, dry sub-humid zone, 695 m above mean sea level. The soil of the experimental location is a deep black soil of the order Vertisols, slightly alkaline in reaction (pH 7.4) and the EC measured in 1:2.5 soil:water suspension was non-saline (< 0.4 dS/m). Study site soil nutrient contents were low available N (208 kg/ha), medium available P_2O_5 (35 kg/ha), and high available K_2O (350 kg/ha), with secondary and micronutrients rated adequate. A high-yielding maize hybrid (Cargill M-900, planting geometry 60 x 20 cm) and wheat (var. DWR-162, spacing 25 x 10 cm) were grown in a sequence starting from

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

kharif 2009, with maize grown in kharif season followed by wheat in rabi 2009. Field experiments were conducted on a fixed site for six consecutive years (from 2009-10 to 2014-15) to determine the response to P application and quantify the agronomic and economic benefits of P fertilizer use in the MWCS. The treatments included i) ample NPK rates (250-120-120 $N\text{-}P_2O_5\text{-}K_2O$ kg/ha for maize and 150-110-100 kg/ha for wheat), ii) P omission (250-0-120 $N\text{-}P_2O_5\text{-}K_2O$ kg/ha for maize and 150-0-100 kg/ha for wheat), iii) Site-Specific Nutrient Management (SSNM) (200-90-100 $N\text{-}P_2O_5\text{-}K_2O$ kg/ha for maize and 120-60-50 kg/ha for wheat) and iv) Farmers' Fertilization Practice (FFP) (115-52-45 $N\text{-}P_2O_5\text{-}K_2O$ kg/ha for maize and 70-50-60 kg/ha for wheat). All the four treatments were replicated thrice in a randomized block design.

Nutrient levels in the SSNM treatment were calculated based on the QUEFTS model (Janssen et al. 1990). Slightly higher rates above the SSNM rates were considered in ample NPK treatment to avoid any nutrient limitation that might hinder achieving the targeted yields and to encourage full expression of crop response. Nutrient application under FFP for maize and wheat were decided based on farmers' participatory survey conducted with ten maize-wheat growing farmers in the study region, and the average value for N, P and K rates were used for FFP.

Except for variation in nutrient application among the treatments, standard crop management practices were followed in all the four treatments in both maize and wheat. Yield observations were recorded in all the treatments for both the crops, and the average of six years data is reported in this paper. System productivity (in terms of maize equivalent yield) is reported, which was calculated as:

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

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

P response (kg/ha) = grain yield in ample NPK (kg/ha) – grain yield in P omission (kg/ha)

Yield attributing parameters were documented under agronomic benefits. Gross returns, net returns and Return on Investment (ROI) was discussed under the economic benefits of P fertilizer use. ROI was calculated as:

$$\text{ROI} = \frac{\text{Yield increase due to P fertilizer (kg/ha) x MSP of crop (Rs/kg)}}{\text{Applied } P_2O_5 \text{ (kg/ha) x cost of } P_2O_5 \text{ (Rs/kg)}}$$

Minimum Support Price (MSP) of maize and wheat, fertilizer prices used in the calculation of ROI were given in **Table 1**.

Table 1. Minimum support price of maize, wheat and prices of fertilizer P used in the calculations.

Price, Rs./kg	2009	2010	2011	2012	2013	2014
SSP* (50 kg bag)	168	197	197	360	360	360
P_2O_5	10.5	12.3	12.3	22.5	22.5	22.5
Maize	8.8	8.8	9.8	11.7	13.1	13.1
Wheat	10.8	11.7	12.8	13.5	14.0	14.5

Source: Tehsil Agricultural Produce Co-operative Marketing Society Limited, Dharwad, Karnataka. *SSP = single superphosphate.

Table 2. Yield of maize, wheat, and maize-wheat system as influenced by different nutrient management options.

Treatment*	Maize yield, t/ha	% Increase over FFP	Wheat yield, t/ha	% Increase over FFP	M-W system productivity in terms of MEY, t/ha
Ample NPK	7.4	72	3.8	19	12.0
P omission	6.2	44	3.5	9	10.4
SSNM	6.9	60	3.7	16	11.2
FFP	4.3	-	3.2	-	8.2
C.D. (p=0.05)	0.868		0.146		

*SSNM = site-specific nutrient management. FFP = farmers' fertilizer practice.

Grain Yield of Maize, Wheat, and MWCS

Pooled results from the experiment, averaged over six years (2009-14) on grain yield of maize, wheat and MWCS (**Table 2**) revealed that highest yields for both maize and wheat, and highest system productivity, were achieved in the ample NPK treatment, followed by the SSNM treatment. Significantly higher grain yield of maize over wheat, even with the supply of adequate rates of nutrients in Northern Karnataka, may be attributed to the combined effect of higher yield potential in maize and generally lower yield potential of wheat in peninsular India as compared to the traditional wheat growing areas of the Northern Indo-Gangetic Plains (IGP). In Northern Karnataka, wheat is cultivated under retreating soil moisture conditions, with a short maturity period of 100 to 110 days, continuously exposed to high temperatures. As a consequence there is poor tillering, fewer grains per spike, and the productivity is only around 2 t/ha, even though the low yields are compensated by high protein of the grain (Nagarajan, 2009). Omission of P from the ample NPK treatment reduced yield by about 1.2 and 0.3 t/ha in maize and wheat, respectively, indicating a greater response to applied P in maize than wheat, possibly due to a combined effect of higher yield potential in maize and more responsive nature of maize than wheat to applied P. An earlier on-farm study in the IGP, however, reported almost similar response of wheat (0.96 t/ha) and maize (0.85 t/ha) to P omission (Jat et al., 2012). The results in the current study (**Table 2**) also indicated that the grain yield in ample NPK, SSNM and P omission treatments was higher than the FFP by 72, 60 and 40% in maize and 19, 16 and 9% in wheat. These observations suggested significant opportunity for improved nutrient management strategy relative to current FFP.

Temporal Variation of P Response

In maize, the grain yield response to application of P varied from 696 to 1,598 kg/ha with an average of 1,275 kg/ha. In wheat, the grain yield response varied from 162 to 707 kg/ha, with an average of 301 kg/ha. These results indicate a greater response to applied P in maize than in wheat in Karnataka (**Table 3**). It was interesting to note that the grain yield response to P decreased over the years of the study. After five years of continuous maize-wheat cultivation, the extent of decrease of P response in the omission plot was 56% in maize and 77% in wheat. The decrease in P response was associated with a decrease in agronomic efficiency of P (kg grain/kg P), which decreased from 13.2 to 8.6 in maize and 6.4 to 1.5 in

Table 3. Temporal variation of P response, P uptake and soil available P in maize-wheat cropping system.

Crop	Treatment	2009	2010	2011	2012	2013	Mean
				P response, kg/ha			
Maize	Ample NPK-P omission	1,584	1,598	1,341	1,157	696	1,275
Wheat	Ample NPK-P omission	707	191	224	218	162	301
				P uptake, kg/ha			
Maize	Ample NPK	54.4	66.4	54.8	57.5	62.4	59.1
	P omission	26.9	29.1	27.5	26.0	27.9	27.5
Wheat	Ample NPK	33.9	37.4	34.2	35.9	37.6	35.8
	P omission	18.6	24.3	21.3	22.1	22.7	21.8
				Available P_2O_5, kg/ha			
Maize	Ample NPK	35.9	36.8	35.4	42.1	44.9	39.0
	P omission	29.7	30.8	28.0	22.2	23.0	26.7
Wheat	Ample NPK	38.8	38.9	38.0	39.7	38.5	38.8
	P omission	32.6	31.9	29.1	27.2	28.7	29.9

wheat during 2009-13, indicating lower P use efficiencies at the applied P rates (data not shown).

The decrease in P response in spite of no application of P for five years may be attributed to an almost constant P uptake of 28 and 22 kg/ha in maize and wheat, respectively (**Table 3**). In maize, P uptake in the P omission treatment (26.9 kg/ha) was 50% of the P uptake in the ample NPK treatment (54.4 kg/ha) at harvest of maize in the first year, and later reduced to 45% after continuously growing maize for five years, with a reduction of only 5% in the P uptake. Whereas, in wheat, the P uptake in the P omission treatment (18.6 kg/ha), which was 55% of the P uptake in the ample NPK treatment (33.9 kg/ha), was increased by 5% after five years of continuous harvest of wheat. The increase in P uptake, in spite of continuous omission of P for five years both in maize and wheat, may be attributed to a constant supply of readily available P to both maize and wheat from the soil. The soil available P_2O_5 in the P omission treatment, tested after the harvest of maize in the first year was 29.7 kg/ha that was later reduced to 23 kg/ha at the fifth year of harvest of maize, with a reduction of 6.7 kg/ha (**Table 3**). Similarly, in wheat, the soil available P_2O_5, which was 32.6 kg/ha in the P omission treatment after the first year of harvest of wheat was reduced by 3.9 kg/ha and remained at 28.7 kg/ha, respectively. This indicated that the soil available P was still medium in availability in spite of continuously growing maize and wheat for five years without application of any P to the soil. The initial P rated medium in these deep black soils with alkaline soil reaction (pH 7.4) was able to continuously supply P to the plants inspite of omission of P application in consecutive five crop cycles. Deshpande et al. (2014) recently observed similar increased availability of P as compared to the initial status in a Vertisol in Maharashtra under cotton cultivation. The authors ascribed the increased availability of P to increased root activity, and the effect of root exudates (low molecular weight organic acids) on P dynamics in Vertisols. However, the results reported in this study are from an on-station experimental site where the soils generally retained the medium available P status due to application of higher rates of P in previous experiments. The situation may be entirely different in farmer fields, where some farmers do not even consider applying P fertilizers in the entire nutrient management program, or apply inadequate and unbalanced rates of P due to lack of awareness. Timsina et al (2010) suggested that response to applied P must be included as a criteria while determining P application rates. In the current study, P response, P uptake and soil available P_2O_5 were critical in determining the P application rates while continuously growing maize-wheat in the deep black soils of Northern Karnataka. The depletion of about 11 kg P_2O_5 from the native soil P due to continuous cultivation of maize and wheat for five consecutive crop cycles without application of P emphasizes the importance of P application to MWCS for sustaining crop yields while maintaining the native soil fertility.

Agronomic and Economic Benefits of P Fertilizer Use

There were temporal differences in various agronomic parameters within the treatments during the study that led to the differences in final grain yield (**Table 4**). In case of maize, the agronomic parameters such as plant height, cob weight, and 100 seed weight were higher in the ample NPK and SSNM plots compared to that in the P omission and FFP treatments. Similarly, in the case of wheat, plant height, number of tillers/m^2, and 100 seed weight were superior in the treatments with adequate P application rates (**Table 4**). Economic analysis of data indicated significantly higher gross and net returns with ample NPK and SSNM treatments over P omission and FFP in maize, whereas, the difference in net returns of wheat between the treatments were statistically non-significant (**Table 4**).

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 SSP fertilizer (**Table 1**). ROI on P fertilizer in maize ranged from 3.4 to 11.1 Rs/Re with a mean of 7.15 Rs/Re (**Table 4**). Similarly,

Table 4. Effect of phosphorus nutrition on agronomic and economic performance of maize-wheat cropping system during 2009-14.

Treatment*	Plant height, cm	Cob weight, g	100 seed weight, g	Gross returns, Rs./ha	Net returns, Rs./ha
			Maize		
Ample NPK	186	133	37	81,493	61,349
P omission	178	123	33	68,482	52,076
SSNM	185	130	36	75,466	57,120
FFP	160	89	31	49,109	33,788
C.D. (*p*=0.05)	7.2	11.8	1.6	8,120	7,013
Treatment*	**Plant height, cm**	**Tiller No./m^2**	**100 seed weight, g**	**Gross returns, Rs./ha**	**Net returns, Rs./ha**
			Wheat		
Ample NPK	68	721	7.8	56,004	39,166
P omission	63	676	7.1	52,170	38,083
SSNM	65	689	7.5	53,762	38,924
FFP	56	451	6.3	45,255	32,958
C.D. (*p*=0.05)	2.9	71.4	0.5	2,732	ns

*SSNM = site-specific nutrient management. FFP = farmers' fertilizer practice.

the ROI on P fertilizer in wheat ranged from 0.9 to 6.6 with a mean of 2.2 Rs/Re, respectively. ROI decreased over the years, registering a high ROI during the initial years. The ROI due to P fertilizer application in maize and wheat was calculated based on the ample rates of P (120 and 110 kg/ha P_2O_5 in maize and wheat) that were applied to ensure no hidden limitation of nutrients. Such high nutrient rates usually give a lower estimate of economic return. The escalating P_2O_5 prices (**Table 1**) also attributed to low ROI, when there is no significant increase in the minimum support prices (MSP) of the crops. Nevertheless, the overall ROI of 9.4 Rs/Re in MWCS signifies the economic benefit of applying P fertilizer in the MWCS.

Table 5. Return on investment (ROI) with P nutrition in maize-wheat cropping system.

	----------- Return on Investment, Rs/Re -----------						
Crop	2009	2010	2011	2012	2013	2014	Mean
Maize	11.06	9.52	8.89	5.04	3.38	5.01	7.15
Wheat	6.61	1.65	2.13	1.19	0.92	0.94	2.24
M-W System	17.67	11.17	11.02	6.23	4.30	5.95	9.39

Summary

The study highlighted that P application in maize and wheat is essential in the deep black soils of Northern Karnataka, and that application of the right rates of P could significantly increase grain yield of maize and wheat while improving the economic returns. Although the pooled grain yield of maize and wheat during the six years of M-W cycle was significantly higher in the ample NPK and SSNM treatments over P omission and FFP, the P response of maize decreased from 1,584 kg/ha in 2009 to 696 kg/ha in 2013, and the P response of wheat also decreased from 707 to 162 kg/ha during the same period. Thus, practicing site-specific P management based on yield response to P application, while understanding the dynamics of P uptake, and considering the ROI on P use, can help in improving the yield and profitability of MWCS in the deep black soils of Northern Karnataka. BC-SA

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IPNI Appoints Phosphorus Program Director

The International Plant Nutrition Institute (IPNI) has appointed Dr. Tom Bruulsema as its Phosphorus Program Director.

"This change in focus reflects a need to devote greater attention to phosphorus, its role in global food security, and its potential for unintended environmental impacts," explained IPNI President Dr. Terry Roberts. "Tom has been directing IPNI programs in the Northeast for 21 years and will continue his involvement and leadership on 4R nutrient stewardship and sustainability issues."

All IPNI scientists' activities include agronomic programs that address phosphorus, nitrogen, potassium and other plant nutrients, and 4R Nutrient Stewardship is a strategic component of the Institute's regional and global tactical plans. Having a Phosphorus Program Director will provide a point person to lead the Institute's ongoing efforts in ensuring phosphorus is used effectively and efficiently.

Dr. Bruulsema has been recognized as a Fellow of the American Society of Agronomy, the Soil Science Society of America, and the Canadian Society of Agronomy. He will continue to be based in Guelph, Ontario, Canada. BC

Dr. Tom Bruulsema
Phosphorus Program Director