BETTER CROPS
SOUTH ASIA

A Publication of the International Plant Nutrition Institute (IPNI) Volume 9, Number 1, 2015

Special Focus Issue on Phosphorus

In This Issue...

IPNI

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BETTER CROPS–SOUTH ASIA

Volume 9, Number 1, December 2015

Our cover: Phosphorus deficiency in maize.

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BETTER CROPS–SOUTH ASIA is a publication of the International Plant Nutrition Institute (IPNI). The mission of IPNI is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family.

The Government of Saskatchewan, Canada, helps make this publication possible through its resource tax funding. We thank them for their support of this important project.

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Printed in India

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Welcome...

You are reading the ninth annual issue of *Better Crops South Asia*. This publication is released in the fourth quarter of each year, and follows a format similar to our flagship publication *Better Crops with Plant Food*.

Our 2015 issue is focused on phosphorus (P).

The research featured in this issue is a tribute to the scientific progress that is continually being made in the fields and laboratories throughout South Asia. Once again, we at IPNI wish to congratulate and thank the many cooperators, researchers, farmers, industry representatives, and others who are working for the benefit of agriculture in South Asia.

Dr. Terry L. Roberts, President, IPNI

IPNI Scholar Award Recipients - 2015

The International Plant Nutrition Institute (IPNI) has selected the winners of the annual Scholar Award Program. A total of 37 graduate students, representing 13 countries, were chosen in 2015. Each winner receives the equivalent of US$2,000. In the South Asia region, IPNI selected eight Scholars whose details are provided below.


Lakshmi D. Maddukuri

Ms. Lakshmi Durga Maddukuri, Indian Agricultural Research Institute, New Delhi, India is obtaining a Ph.D. in floriculture and landscaping. Her dissertation title is "Development of Site-Specific Integrated Nutrient Management Systems for Gladiolus and Marigold using Soil Test Crop Response Correlation Studies." Her project objectives include, developing soil test based recommendations of nitrogen, phosphorus, and potassium for specific levels of yield targets of gladiolus and marigold. She plans to continue her research and work with farmers to improve soil fertility and nutrient use efficiency.


Kali Krishna Hazra

Mr. Kali Krishna Hazra, Indian Institute of Technology Kharagpur, West Bengal, India is completing his Ph.D. in agronomy. His dissertation title is "Assessment of Soil-plant Phosphorus Dynamics in Aerobic Rice-lentil Production Systems for Strategic Phosphorus Management." The goal is to address the issue of reduced phosphorus availability under non-flooded rice cultivation practices such as the System of Rice Intensification (SRI) and Direct Seeded Rice. Mr. Hazra plans to conduct more research related to crop and soil related issues.


Muhammad Imran

Mr. Muhammad Imran, Bahauddin Zakariya University, Multan, Punjab, Pakistan, is obtaining his Ph.D. in soil science. His dissertation title is "Phosphorus Management for Biofortification of Zinc in Maize Grown on Calcareous Soils." Muhammad's goals include, finding the fixation and retention capacities of Zn and P in different textured soils by the Michaelis-Menten adsorption model as a function of time, management of P to increase Zn bioavailability in maize grains, and different Zn fertilization approaches in terms of improving estimated Zn bioavailability in humans. Mr. Imran wants to pursue more research on Zn bio-fortification of cereals and work to alleviate mineral malnutrition in humans.


Basavaraj Patil

Mr. Basavaraj Patil, University of Agricultural Sciences, Dharwad, Karnataka, India, is pursing a Ph.D in agronomy. His dissertation title is "Precision Nutrient and Water Management in Sugarcane." In India, the average productivity of sugarcane is relatively low. Site-specific nutrient management strategies have produced tangible yield gains, along with higher efficiency and improved soil health, but the process is quite intensive and feasible in small domains only. The present investigation aims at precision water and nutrient management for achieving the target yield of sugarcane by taking into consideration soil spatial variability. Mr. Patil plans to become a research scientist and continue his work in the area of precision nutrient management.

Amrita Sengupta

Ms. Amrita Sengupta, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India, is working towards her Ph.D in agronomy. Her dissertation title is "Enhancement of Groundnut Productivity through Isolated Rhizobia and Phosphate Solubilizing Bacteria." In India, Groundnut is mostly grown under energy starved conditions and microbial interventions can therefore be a sound strategy for enhancing productivity. She is working on isolation, characterization and successful utilization of some new microbial strains to increase the productivity of groundnut, by partial replacement of inorganic fertilizers. Ms. Sengupta plans to extend her research in an interdisciplinary manner, preferably in the fields of agronomy, soil science and plant breeding, with the goal of improving soil and crop management and preserving natural resources.

Abhijit Sarkar

Mr. Abhijit Sarkar, Agricultural Research Institute, New Delhi, India, is earning his Ph.D. in soil science. His dissertation title is "Development and Characterization of Superabsorbent Controlled-release Nitrogen-Phosphorus (NP) fertilizer Formulations and Their Impact on Soil Health under Rice-wheat Cropping System." Nitrogen and P are two of the most important nutrients for plant nutrition, but various environmental challenges are associated with excess losses from conventional fertilizers. One possible solution is the development of superabsorbent controlled release NP-fertilizer that supplies nutrients in accordance with plant demand. Mr. Sarkar's research interests include nutrient management, nanotechnology, and environmental sciences. He would like to develop fertilizer products with improved nutrient use efficiency.

Dibakar Ghosh

Mr. Dibakar Ghosh, Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal, India, is completing his Ph.D. in agronomy. His dissertation title is "Weed and Nutrient Management in Maize-greengram (Residual)-rice Crop Sequence under New Alluvial Soil." The project examines combined weed and nutrient management in maize-greengram-rice crop sequence under new alluvial soil to assess the treatment combinations relating to their effects on weed flora and their growth, productivity, and quality of crops in sequence, and nutrient mining by crops and weeds. His future interests include developing environmentally and economically beneficial sustainable technologies for farmers.

Ashok K. Koilakonda

Mr. Ashok Kumar Koilakonda, Indian Institute of Technology, Kharagpur, West Bengal, India, is earning a Ph.D. in agronomy. His dissertation title is "Comparative Assessment of Direct and Carry-over Effects of Organic and Inorganic Nutrient Management for Rice-chickpea Production System in Lateritic Soil." The study focuses on selecting the right source of nutrients such as vermicompost and chemical fertilizers as a source of nutrients, the right quantity of nutrients with varied levels of organic and inorganic fertilizers, and the right time of application like basal and split application of organic and inorganic fertilizers. He would like to focus on site-specific nutrient management and provide recommendations to the region's rice growers.

Graduate students attending a degree-granting institution located in any country within an IPNI regional program are eligible. The award is available to graduate students in science programs relevant to plant nutrition science and the management of crop nutrients including: agronomy, horticulture, ecology, soil fertility, soil chemistry, crop physiology, environmental science, and others.

Regional committees of IPNI scientific staff select the recipients of the IPNI Scholar Award. The awards are presented directly to the students at a preferred location and no specific duties are required of them.

Funding for the scholar award program is provided through support of IPNI member companies, primary producers of nitrogen, phosphate, potash, and other fertilizers.

More information is available from IPNI staff, individual universities, or from the IPNI website: www.ipni.net/awards. BCSA

Phosphorus Management in Crops and Cropping Systems in India – A Review

By S.K. Sanyal, B.S. Dwivedi, V.K. Singh, K. Majumdar, S.C. Datta, S.K. Pattanayak, and K. Annapurna

Low to medium soil test P levels across India have increased the need to address the deficiency of P in achieving economic crop production.

Phosphorus additions to soils are dependent on not only adequate supplies of N, but also K, S and micronutrients to address the growing issues of multi-nutrient deficiencies limiting crop yields.

Increasing cost of fertilizer P has focused attention on how to improve P-use efficiency in a way that optimizes both crop and economic responses.

Phosphorus (P) is essential for all forms of life and is equally important for its contribution in aiding the native soil fertility and sustaining it, especially under intensive agriculture. The economic challenges associated with increasing P fertilizer prices are driving the increased interest in improving P use efficiency (Sanyal et al., 2015). Moreover, transfer of soil P from cultivated land through erosion or runoff is a major cause of P-induced eutrophication in surface waters. A judicious site-specific P management strategy is required to ensure optimum crop yield with lesser environmental footprint.

Data on available P content of surface (0 to 15 cm) soil has been compiled from time to time (**Table 1**) that provide a measure of P fertility of Indian soils. Thus, soils of more than 90% of the districts represented low to medium P fertility categories, indicating the necessity of P fertilization to produce optimum crop yields. Although, it may not be rational to assess the changes in P fertility status over time from these data as districts and locations of sampling may differ considerably, these data clearly indicate that P fertility of most of the Indian soils continues to be extremely poor. A recent publication based on omission plot trials in the Indo-Gangetic Plains showed that average yield loss due to no application of P fertilizer could be 712, 969, and 853 kg/ha in rice, wheat, and maize, respectively (Jat et al., 2012). Also, wide inter-regional variations exist in P fertility of soils, which are often masked in summarized country-level reports.

Table 1. Phosphorus fertility status of Indian soils.

Reference	Districts studied	% of districts in fertility categories* Low	Medium	High
Ramamoorthy and Bajaj (1969)	226	47	49	4
Ghosh and Hasan (1979)	363	46	52	2
Muralidharudu et al. (2011)	500	51	40	9

*A soil analyzing less than 10 kg P/ha (Olsen-P value) is categorized as low, between 10 to 25 kg P/ha as medium, and over 25 kg P/ha as high in P availability.

Several methods for determining available soil P have been developed to provide a basis for fertilizer recommendations (Fixen and Grove, 1990). Generally, the P soil test data are categorized in different fertility classes, based on soil fertility ratings (low, medium and high), proposed during the 1950s on the basis of magnitude of crop response to nutrient input. These ratings remained almost unchanged although the entire spectrum of agriculture has been transformed since then, particularly with respect to P removal and response pattern of exhaustive crop varieties. When crop responses to P application are similar for both 'medium' and 'low' P soils, as indicated by multi- locational on-farm experiments (**Table 2**), a fertilizer prescription formulated for such a 'medium' fertility soil would be essentially sub-optimal for a low fertility soil. Hence, these ratings need to be revised in the light of current crop responses to applied P on different soils, and used for interpretation of soil test data.

Table 2. Average response of wheat to 60 kg P_2O_5/ha in on-farm trials on the soils of low, medium and high fertility status.

Fertility rating	Districts	Trials	Response, kg/ha
Low	21	2,140	680
Medium	17	2,446	669
High	1	147	486

Source: Tiwari (2006)

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

Phosphorus Removal under Dominant Cropping Systems

On-farm studies conducted under the All India Coordinated Research Project on Integrated Farming Systems (AICRP-IFS, earlier AICRP-CS) have clearly shown that P uptake was maximum in crops when all the macro and micro-nutrients were applied in optimum amounts. Application of P along with N increased P uptake by 21 to 25% in rice-wheat, 10 to 13% in rice-rice, 30 to 34% in maize-wheat, 12 to 40% in pearl millet-wheat, and 23 to 26% in cotton-wheat system in *kharif* and *rabi* crops, respectively over N application alone. The added increase due to K over NP was 9 to 33% under different cropping systems. Skipping micro-nutrients resulted in 11 to 34% lower P uptake under these cropping systems. Comparatively lower P uptake under farmers' fertilizer management practice (FFP) may be ascribed to the continuous neglect of K, S and micro-nutrients (Singh et al., 2013). On Typic Ustochrept soils of Modipuram, combined use of 120 kg N and 26 kg P/ha in rice and wheat not only produced high yields compared with addition of N alone, but the agronomic efficiency and apparent recovery of fertilizer N and P in rice and wheat also increased significantly (Singh et al., 2010).

Sharp decline in yield with P omission in on-farm trial.

Phosphorus deficiency symptions on exposed, erosion-prone soil.

Phosphorus Management Strategies under different Cropping Systems

Fertilizer P management in rice-wheat system (RWS) is of particular significance because of distinct growing conditions of rice and wheat that lead to alternate anaerobic and aerobic soil environments. In rice, submergence creates reducing conditions, which leads to reduction of ferric phosphate to ferrous phosphate, resulting in a greater availability of P in the soil (Sanyal and De Datta, 1991). Organic acids formed under submerged conditions also solubilize phosphates. 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 then AICRP-IFS, no definite conclusion could be drawn as to whether P should be applied to wheat or rice or to both crops. On loamy sand soils of Ludhiana, flooded rice did not respond to applied P, but the subsequent wheat crop did. Fairly recent studies on similar soils have, however, shown that the best approach is to apply P to both crops (Singh et al., 2002). 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, 1994). In view of varying reports, skipping of P to rice in RWS would depend on soil type, its P supplying and buffering 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 system yield (6 t/ha rice and 5 t/ha wheat) immediately falls under P responsive category with increasing production targets. Accordingly, P requirements increased for both rice and wheat crops. Optimum P fertilizer rates (P-opt) ranged between 14.6 and 27.7 kg/ha for rice, and from 19.4 to 32.7 kg/ha for wheat at different locations. A tremendous increase in the agronomic efficiency of applied P (AE_p) in rice and wheat, such as 38.6 to 70.2 kg grain/kg P and 22.7 to 37.4 kg grain/kg P, respectively, was noted when all the deficient nutrients (macro and micro- S, Zn, B) were applied for attaining high yield targets. In the on-farm studies also, partial factor productivity (PFP_p) and AE_p were maximum with balanced NPK fertilization under different predominant cropping systems (**Table 3**). Conjunctive uses of S and Zn with P have pronounced effect on P responses and use efficiency in many crops at various locations of AICRP-IFS (AICRP-IFS, Reports). Studies conducted on direct application of ground phosphate rock (GPR) on neutral Typic Ustochrept revealed that instead of applying GPR at the recommended rate to each crop, heavy initial dressings of P rates, recommended for 4 to 6 rice or wheat crops, is a promising option. Inoculation with *A. awamori* culture, i.e., root-dipping of rice seedlings and seed treatment of wheat further improved P availability from GPR, annual productivity and net profits (Dwivedi et al., 2004).

Analysis of multi-location long-term experiments (LTEs), conducted under AICRP-IFS, indicated a highly significant (*p*

Table 3. Partial factor productivity and agronomic efficiency of P as influence by balanced fertilization under different cropping systems.

		Partial factor productivity of P, kg grain/kg P				Agronomic efficiency of P, kg grain/kg P			
	No. of	---- 1st crop ----		---- 2nd crop ----		---- 1st crop ----		---- 2nd crop ----	
Cropping system	trials	with N	with NK	with N	with NK	with N	with NK	with N	with NK
Rice-rice system	1,830	107.1	124.9	91.9	107.8	19.8	34.3	19.1	33.3
Rice-wheat system	1,805	90.4	100.8	56.6	65.1	23.5	31.0	14.5	21.8
Pearl millet-mustard system	212	54.4	59.1	44.8	49	13.0	20.2	12.6	15.6
Maize-wheat system	1,010	66.4	75.6	70.7	81.1	18.8	27.8	22.3	31.1
Soybean-wheat system	395	22.8	26.5	51.7	61.3	3.6	7.0	9.1	17.2
Pearl millet-wheat system	146	48.1	59.3	60.7	71.5	14.5	25.3	15.9	25.3
Cotton-wheat system	56	49.9	53.4	69.3	73	19.1	21.2	27.7	32.4
Rice-maize system	12	85.8	100.5	63.7	88.7	18.9	33.1	12.8	27.4

Source: AICRP-IFS, 2001-2010

< 0.01) increase in yield of rice with integrated use of fertilizers and manures, suggesting thereby the advantage of the integrated plant nutrient supply system (IPNS) over sole use of NPK fertilizers in sustaining crop yields. As traditional organic manures are not available in adequate amounts, possibilities of inclusion of legumes in RWS may become a viable option for efficient P management strategies. Studies conducted by Dwivedi et al. (2003) revealed that forage cowpea grown during post-wheat summer on residual soil fertility increased the AE_P 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, besides raising wheat yield and soil organic matter content. In another study, substitution of pigeon pea in place of rice enhanced wheat yields and NP use efficiency, owing to a 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., 2010).

Recent studies, conducted in the Western Plain zone (Dwivedi et al., 2004; Singh et al., 2010), indicated that around 61% of large farmers (≥ 4 ha farm size) burn rice residue partially or completely in their field. In such situations, use of the Happy/Turbo seeder machine for wheat was found to be a better option, which recycles the whole rice residue without any yield penalty (AICRP-IFS Report, 2011-12). The other options like furrow-irrigated raised bed (FIRB), permanent raised bed (PRB) and zero-till seeding are promising options. Field experiments on Typic Ustochrept of Western IGP by Singh et al. (2010) revealed that the economic optimum doses of fertilizer N and P for wheat in the pigeon pea–wheat system were smaller (128 kg N and 28 kg P/ha) under permanent raised bed (PRB) as compared to flat-bed (FB) (152 kg N and 30 kg P/ha) owing to the increased N and P supply, greater P use efficiency and a better crop growth environment, along with higher Olsen P content under PRB planting.

Economics of P Fertilization

Phosphorus is the costliest among the major plant nutrients applied through fertilizers. Nonetheless, yield responses to fertilizer P are often substantial, making P application an economically remunerative option. On-farm studies conducted under AICRP-IFS revealed substantial net return on investment in P fertilizer [Rs. 8.05 to 16.72 per rupee invested (Rs/Re) in fertilizer P_2O_5] in different cropping systems during 2004-06. The P fertilizer price hike by 2.5 to 3 times during the recent time, however, led to decline in economic returns (1.47 to 5.17 Rs/Re in P_2O_5) (**Figure 1**). Amongst the cropping systems compared, lowest economic returns on P usage were obtained with pearl millet-mustard system. Although P application continues to be remunerative despite increased price of P fertilizer, the drop in economics of P fertilization in recent years underlined the significance of enhancing P use efficiency through adoption of appropriate management practices (Singh, 2013).

Summary

Soils vary widely in their capacities to supply P to crops in view of the fact that only a small fraction of the total P in soil is available to crops. Thus, the crop growth and yield are likely to suffer adversely unless soil is endowed with adequate native supply of plant-available P, or else the soil receives readily available (inorganic) P fertilizers. The present article analyzes P management in important crops and cropping systems of India to underline the importance of fertilizer P application to support sustained high productivity for ensuring food security. BC-SA

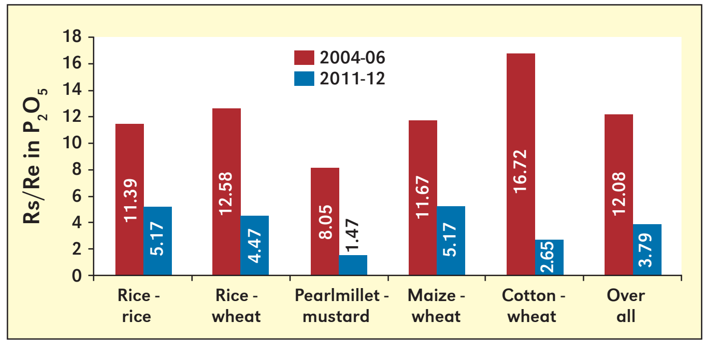

Figure 1. Change in net return invested on P (Rs/Re) due to increase in phosphate fertilizer prices between 2003-06 and 2011-12. Source: Singh, 2013.

Dr. Sanyal was formerly at Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal; Drs. Dwivedi, Datta and Annapurna are with Indian Agricultural Research Institute, New Delhi; Dr. Singh is with ICAR-Indian Institute of Farming Systems Research, Modipuram, Meerut, Uttar Pradesh; Dr. Majumdar (e-mail: kmajumdar@ipni.net) is with IPNI South Asia Program at Gurgaon, Haryana; and Dr. Pattanayak is with Orissa University of Agriculture & Technology, Bhubaneswar, Odisha.

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Farm Typology-based Phosphorus Management for Maize in West Bengal

By H. Banerjee, R. Goswami, S.K. Dutta, S. Chakraborty, and K. Majumdar

Integrating the farmers' resource endowment capacity into the nutrient management strategy is important for sustainable maize production systems.

Farm typology-based phosphate fertilizer recommendation demonstrated significant increase in agronomic and economic benefit over the existing management practices in maize growing areas of West Bengal.

Maize is an important field crop of West Bengal in terms of acreage, production and utilization for food and feed purposes. The introduction of hybrid maize has increased the production potential of maize systems. However, the present productivity level of maize across eastern India is very low due to several production constraints at the farm level. Widespread nutrient depletion of agricultural soils is one of the most important bio-physical factors limiting small scale maize production across Asia. Literature suggests that the ability of soil to supply nutrients naturally, as well as nutrient recovery for maize, are location-specific (Witt et al., 2009). Therefore, enhancement of maize productivity can largely be achieved through proper supplementation of plant nutrition. However, the recommendation of fertilizer is a challenge to scientists as it should meet both the nutrient demand of the crop and sustain the crop production system.

The 4R Nutrient Stewardship concept, and its implementation through site-specific nutrient management (SSNM), helps to achieve agronomic and economic benefits while maintaining socially and environmentally sustainable crop production systems. However, to provide appropriate recommendations, a SSNM-based nutrient recommendation needs to be integrated with the classification of farmers as per their resource endowment. Grouping farmers within a domain in different resource endowment classes is an essential step in the realistic evaluation of the constraints and opportunities that exists within farm households for appropriate interventions (Banerjee et al., 2014). The present study was initiated to identify different farm typologies of smallholder maize farmers in southern Bengal, followed by the application of Nutrient Expert® (NE) – a decision support tool for precision nutrient management with a special reference to P nutrition.

Rapid Rural Surveys

Farm typologies were determined based on information derived from a Rapid Rural Survey (RRS) conducted in the four West Bengal districts of South 24 Parganas, Paschim Medinipur, Nadia and Murshidabad (**Table 1**). These four districts represent four distinct agro-ecological zones and are representative of a large part of eastern India in terms of farmers' socio-economic conditions and bio-physical characteristics of their farmlands. The idea was to include two emerging (South 24 Parganas and Paschim Medinipur) and two traditional (Nadia and Murshidabad) maize-growing areas in this study.

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

Experimental field comparing Nutrient Expert® plot (left) and farm practice (right) at Krishnanagar-I block in Nadia districts of West Bengal, India.

Under each district, maize growers were selected randomly from three adjacent villages (**Table 1**). The interview sched-

Table 1. Study locations and number of farmers interviewed.

Districts	Blocks	Villages	Sample
South 24 Parganas	Pathar Pratima	Rakshaskhali, Dakshin Shibjanj	19
	Baruipur	Ghola	13
Paschim Medinipur	Keshpur	Khirishmul, Uchahar, Jorapata	18
	Daspur	Ramdaspur	12
Nadia	Krishnanagar-I	Kulgachhi, Purba Bhat Jangla, Gobindapur, Asannagar	30
Murshidabad	Raghunathganj	Radhakrishnapur	15
	Lalgola	Chanoapara, Champapur	20
		TOTAL	127

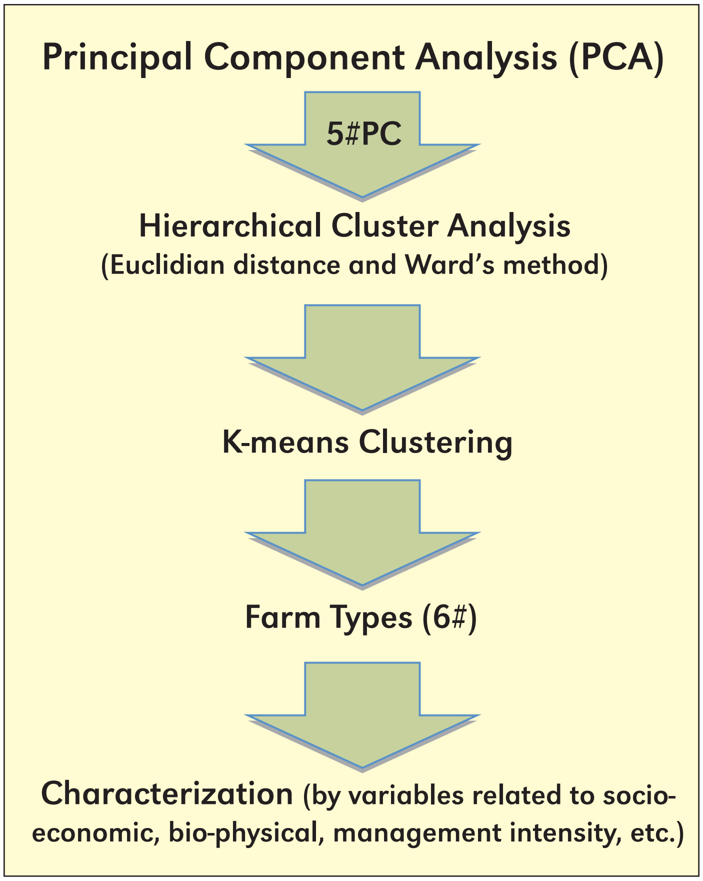

Figure 1. Methodology of farm typology delineation and characterization.

ule was developed and a database was created, manipulated and screened in SPSS, Version 17 (SPSS Inc., Chicago, USA).

Farm Typologies

Multivariate statistical techniques have been widely used for the farm typology and characterization study. Principal Component Analysis (PCA) was used to reduce the number of variables, which was followed by Cluster Analysis to identify typical farm households (Goswami et al., 2014). We used variables related to both socio-economic background and management intensity (labor and input use) of the maize growers in the PCA (**Figure 1**). Then, the five extracted PCs were used to cluster the surveyed farms. A hierarchical cluster analysis using Euclidian distance and Ward's method was used to identify the potential number of clusters (six in our study) and K-means clustering was finally used to classify the surveyed farms. The six farm types were characterized by a host of socio-economic, crop management, and related variables. The distribution of farm types in different districts along with their qualitative description is given in **Table 2**. The identified farm typologies were then used for site-specific nutrient recommendations using NE.

On-farm Trials at Different Locations

A total of 127 trials were conducted during the 2014-15 in the four districts of South 24 Parganas (32), Paschim Medinipur (30), Nadia (30), and Murshidabad (35) to rationalize P use in maize systems. Two maize hybrids namely PAC 740 (Grain purpose) and HQPM 1 (Seed purpose) were given to selected farmers for the growing season December-January to April-May.

Table 2. Characterization of identified farm types (narrative form).

Farm Type	No. of farms	Location (No. of farms)
Farm Type 1: Moderate-resourced commercial maize grower	16	Murshidabad (6) Nadia (8) South 24 Parganas (2)
Farm Type 2: Exclusive cultivators with large holding and large family	9	Paschim Medinipur (2) Murshidabad (0) Nadia (2) South 24 Parganas (5)
Farm Type 3: Low-yielding new maize growers	37	Paschim Medinipur (25) Murshidabad (0) Nadia (2) South 24 Parganas (10)
Farm Type 4: Moderately resourced family farms	16	Paschim Medinipur (3) Murshidabad (0) Nadia (0) South 24 Parganas (13)
Farm Type 5: Traditional maize grower	28	Paschim Medinipur (0) Murshidabad (26) Nadia (1) South 24 Parganas (1)
Farm Type 6: Resource-rich commercial seed producers	21	Paschim Medinipur (0) Murshidabad (3) Nadia (17) South 24 Parganas (1)

In order to rationalize fertilizer P application to support sustained high productivity on one hand and address the environmental and economic concerns on the other, P management is an important parameter (Sanyal et al., 2015). NE for hybrid maize has been used in the present study for nutrient management recommendations. NE provides fertilizer recommendations that are consistent with SSNM strategies for managing P fertilizer along with other nutrients. Based on the knowledge of the maximum attainable yield (Ymax), the actual attainable yield (Ya), yield at farmer's field (Y), and the nutrient-limiting yield from a large number of on-farm trial results, NE utilizes decision rules that provides guidance for fertilizer P application to achieve a pre-determined attainable yield at a location with specific indigenous nutrient supplying capacity. The development process and the decision rules used in NE has been explained in details elsewhere (Pampolino et al., 2012).

Phosphorus Requirement of Maize

Maize requires large quantities of P (along with N and K) for higher yields. Production of 1 t of maize removes almost 18 kg P_2O_5/ha (IPNI Data). Plants obtain much of their P from the soil, crop residues, organic amendments, and irrigation water. But the supply of P from these naturally occurring, indigenous sources is typically insufficient to sustain high maize yield. Supplemental P fertilizers are thus essential for sustaining high and profitable yields of maize without depleting the fertility of the soil. The economic challenges associated with increasing P fertilizer prices in India are driving the increased interest in improving P-use efficiency (Majumdar et al., 2013). Moreover, transfer of soil P from cultivated land through erosion or runoff is a major concern. This necessitates appropriate P management for taking care of native soil P supplies and crop

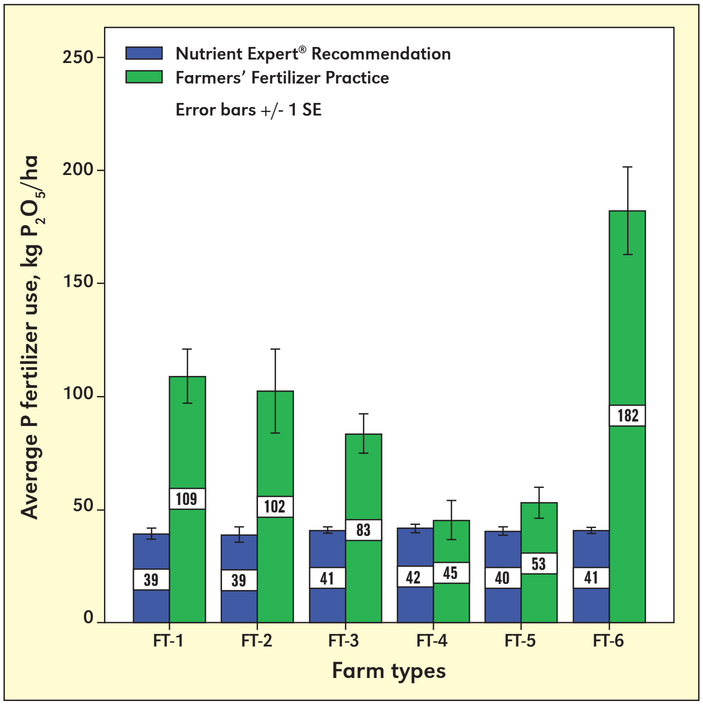

Figure 2. Comparison of P fertilizer use across different farm types, West Bengal.

demands in a growing environment (Sanyal et al., 2015). The SSNM approach advocates the sufficient use of fertilizer P to overcome deficiencies while simultaneously accounting for, to some extent, the nutrient removal with harvested products, to avoid P mining.

Phosphorus Management Strategies and Maize Yield

A comparison of the agronomic and economic performance of NE-based fertilizer recommendation over Farmers' practice (FFP) were carried out to evaluate their performance in smallholder maize growing environments among different farm types across different districts of West Bengal. FFP treatments differed in the amount of P applied among the six farm types. Farmers belonging to farm type 6 demonstrated greater tendencies of applying higher P rates in maize cultivation, followed by farm type 1, 2 and 3. Poor P use was common for growers who belonged to type 4 and 5. The NE tool recommended comparatively lower amounts of P over the FFP across all farm types (**Figure 2**). Compared to FFP, average P use with NE decreased by 178, 164, 105, 9, 32, and 345% from farm type 1 to 6, respectively.

NE and FFP treatments differed in the yield of maize among the six farm types. The NE yields were significantly ($p \leq 0.01$) higher compared to FFP across all the farm types (**Figure 3**). Farmers belonging to farm type 5 achieved the highest maize yields, followed by type 1, 6 and 4. Poor yield was common in growers who belong to type 3 and 2. Compared to FFP, average grain yields in NE-based SSNM increased by 41.7, 47.0, 70.4, 38.3, 55.3, and 62.5% in farm type 1 to 6, respectively. However, it must be pointed out that the yield improvement in the NE treatment was due to the balanced and site-specific application of all limiting nutrients, not only P, at the right time and through use of the right sources. The results showed the potential benefit of using the Nutrient Expert® tool in areas where farmers get lower maize yield due to imbalanced fertilization.

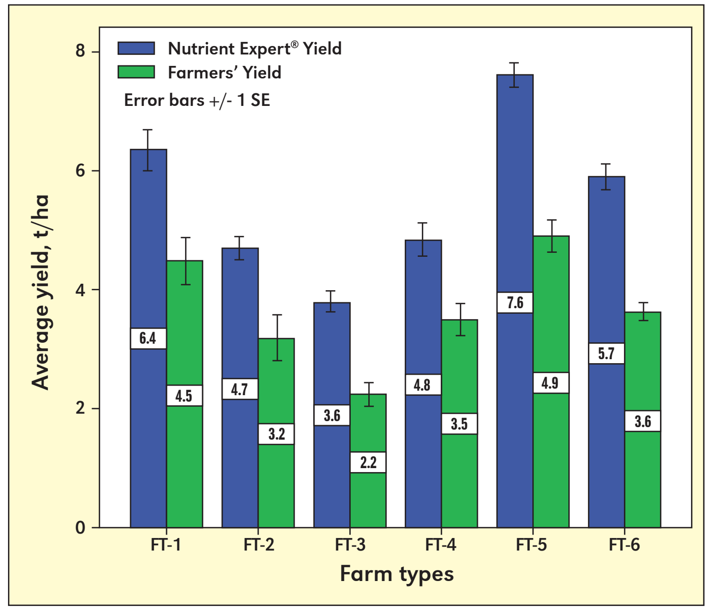

Figure 3. Comparison of yield across different farm types, West Bengal.

Economics of Phosphorus Management

The cost of cultivation in terms of P fertilizer application differed across treatments among the six farm types. Farmers belonging to farm type 6 incurred significantly higher expenditure towards P fertilizer, followed by the farmers on farm types 1, 2 and 3. Maize growers of type 4 and 5 spent comparatively less on P fertilizer. Significantly ($p \leq 0.01$) lesser P fertilizer cost was achieved with NE recommendation across all farm types (**Figure 4**). Compared to FFP, average P fertilizer cost with NE for different farm types decreased to a similar extent to that of P fertilizer use.

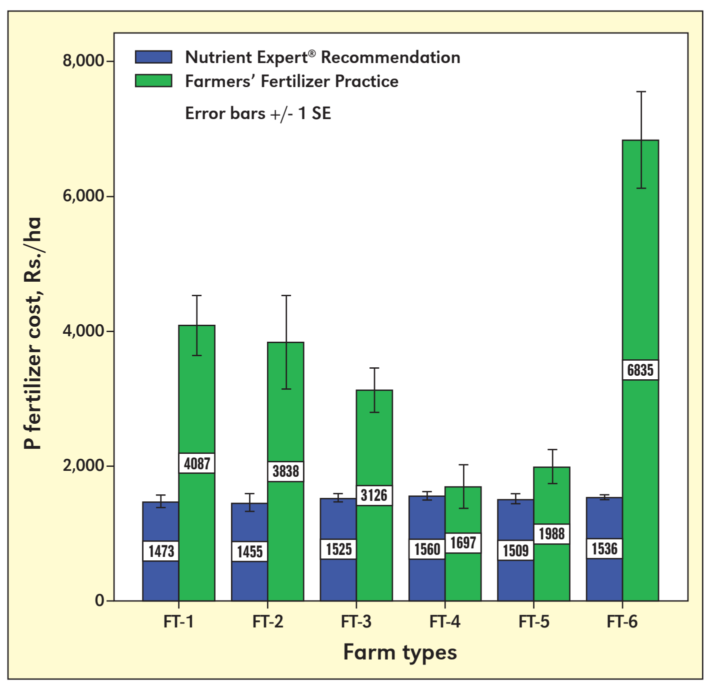

Figure 4. Average P fertilizer cost across different farm types, West Bengal.

IPNI Photo/S. Dutta

Field site inspection by Dr. Dutta (center) standing next to Dr. Banerjee (right in photo) and the site's farmer (left).

Conclusion

Yield and profitability of maize in the favorable tropical environments of eastern India can further be increased with improved nutrient management practices. The farm typology-based nutrient recommendations in this study, in terms of phosphate fertilization, demonstrated a significant increase in agronomic and economic benefit over current farmer fertilizer practices. Nutrient Expert® use in this study supports its wide spread dissemination in support of balanced fertilizer recommendations. BC-SA

Acknowledgment

We are thankful to the MAIZE CRP Program of CIMMYT for providing financial support to conduct this study.

Dr. Banerjee is with the Regional Research Station (CSZ), Bidhan Chandra Krishi Viswavidyalaya, Kakdwip, South 24 Parganas, West Bengal. Dr. Goswami is with IRDM Faculty Centre, Ramakrishna Mission Vivekananda University, Kolkata, India, Dr. Dutta (e-mail: sdutta@ipni.net) and Dr. Majumdar are with the International Plant Nutrition Institute, South Asia Program headquartered in Gurgaon, Haryana. Dr. Chakraborty is with Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal.

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Enhancing Rice Yield, Profitability, and Phosphorus Use Efficiency in West Bengal using the Nutrient Expert® Fertilizer Decision Support Tool

By M.K. Mandal, S. Dutta, K. Majumdar, T. Satyanarayana, M. Pampolino, V. Govil, A.M. Johnston, and G.C. Shrotriya

Nutrient Expert®-based fertilizer recommendation helped increase rice productivity and P use efficiency over farmers' fertilization practice.

Rice is the most important food crop of India. Rice is grown under diverse agro-ecological conditions, in a variety of soils, in combination or in sequence with a large number of crops. Rice ranks first in the use of land at > 43 million (M) ha, water resources (> 50% irrigation water), and inputs (38 to 40% of fertilizers and 17 to 18% of pesticides) among the crops cultivated in India (Rice Knowledge Management Portal, http://www.rkmp.co.in). Grown in an area of 43 M ha with an average productivity of 2.5 t/ha, rice contributes to nearly 41% to the total foodgrain production. The demand for rice is projected to increase in the near future with the increase in population in India. A summary of several projections compiled by the Directorate of Rice Research (2011) showed the demand for rice is expected to rise between 107 to 156 M t by 2030 over the current production of 43 M t (FAI, 2014).

Future gains in rice yield is expected to be largely driven by knowledge intensive crop and soil management as compared to the germplasm driven yield gains since the start of Green Revolution. Development of precision nutrient management strategies for rice grown in different ecologies and seasons in India, and their large-scale adoption through innovative extension mechanisms, will be critical to achieve projected production goals in 2030 that are 3 to 4 times the current production level.

Imbalanced fertilizer application in rice has been identified as one of the major reasons for decreasing crop response to fertilizer application and the consequent lower crop production growth rate in India. Chauhan et al. (2012) identified increasing multiple deficiencies of major nutrients (N, P, K, and S) and micronutrients (Zn, Fe and Mn) due to imbalanced fertilization as one of the major reasons for stagnant or declining yield of rice. The lack of appropriate tools and implementation mechanisms, along with government subsidy programs, has

Abbrevations and notes: N = nitrogen; P = phosphorus; K = potassium; Fe = iron; Mn = manganese; Zn = zinc.

A rice farmer of Hoogly District, West Bengal transplanting her crop.

been a major hindrance that restricted wide-scale adoption of balanced fertilization in rice. Hobbs and Morris (1996) suggested that reduced total factor productivity (input-use efficiency) and profit margin, and increasing cultivation costs in rice production, has led to a loss of relevance of the simple agronomic practices that revolutionized rice-wheat cultivation in the Indo-Gangetic Plain.

IPNI and its partner organizations in South Asia have jointly developed a dynamic nutrient management tool, the Nutrient Expert® (NE) for Rice (India), that can generate farm-specific fertilizer recommendation for rice. The tool is based on the site-specific nutrient management (SSNM) principles (Pampolino et al., 2012) and utilizes information of the growing environment to provide balanced fertilizer recommendations for rice that are tailored for a particular location, cropping system, rice ecology, season, and farmer resource availability.

The NE rice tool development in India was followed by a large-scale on-farm validation across different growing environments of rice. The NE-based recommendations were compared to the existing farmers' fertilization practices (FFP). The two treatments were implemented side-by-side in the same farmer's field where each plot size was ≥100 m^2. The current study reports on the pooled data from 323 on-farm trials in high-yielding variety (HYV) rice from 10 districts of West Bengal, covering old and new alluvial soils, and red and lateritic soils. A single fertilizer recommendation was given to multiple farmers in domains where the soils, cropping systems and FFP did not differ significantly to warrant different recommendations. The validation trials were conducted in collaboration with Iffco Kisan Sanchar Ltd. (IKSL) through their farmer network across West Bengal, in the kharif season of 2014.

The NE-based fertilizer recommendation for rice improved the grain yield as compared to FFP (**Figure 1**) across multiple sites in West Bengal. The highest yields achieved using the NE recommendation and FFP were 7,250 kg/ha and 6,200 kg/ha, respectively. The yield variability across sites was higher in the farmers' practices as compared to the NE treatment due to variable management of farmers. Rice yields were far more stable and varied within a short range as the NE recommendation for each individual farmer was designed to achieve the maximum attainable yield of HYV rice in the kharif season. Other studies using NE for maize and wheat also showed significant yield advantage from the tool-based fertilizer recommendation as compared to existing practices (Satyanarayana et al., 2012; Sapkota et al., 2014).

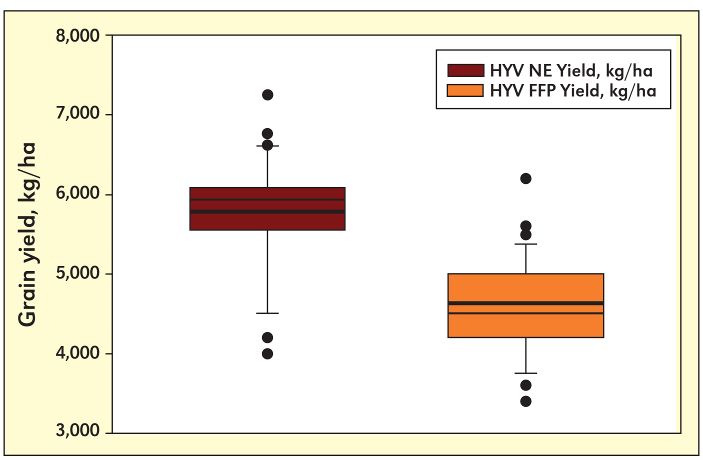

Figure 1. Average high yielding variety (HYV) rice grain yield in Nutrient Expert® (NE) validation trials compared to farmers' fertilization practice (FFP) (n = 323) in West Bengal. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median and the thick line represents the mean. 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.

The NE tool estimates attainable yield in a location based on a constraint analysis that takes into account historical yield data, soil characteristics, and other crop management parameters. In this study, the yield data from the NE treatments were compared with the attainable yields estimated by the NE tool. The analysis showed that 43% of the trials achieved NE estimated attainable yield, yield in 41% trials exceeded the estimated attainable yield, and NE estimated attainable yield was not achieved in 16% of the trials (data not shown).

As mentioned earlier, the NE tool is based on the SSNM principles. SSNM advocates external application of nutrients to bridge the gap between indigenous soil nutrient supply and crop nutrient requirement for a target yield. In smallholder rice fields of West Bengal, farmers' crop and soil management varies widely depending on awareness and resource availability. Such variable management decisions create large spatial and temporal variability in soil nutrient availability. Ideally the fertilizer management in such smallholder landscape should vary and be location-specific to avoid over- or under-use of nutrients. Location specific fertilizer management in such variable landscapes is expected to produce benefits in terms of improved yield, higher nutrient use efficiency or saving of fertilizer and consequent improved economics of production and environmental stewardship of applied nutrients. The comparative data of different treatments from the validation trials for rice are given in **Table 1**.

Table 1. Agronomic and economic performance of Nutrient Expert®-Rice in West Bengal (n = 323).

Parameters	Unit	Farmer Fertilization Practice (FFP)	Nutrient Expert (NE)	NE-FFP	
Grain yield	kg/ha	4,627	5,784	+1,157	***
Fertilizer N	kg/ha	85	111	+26	***
Fertilizer P_2O_5	kg/ha	39	34	-5	*
Fertilizer K_2O	kg/ha	47	49	+2	ns
Fertilizer cost	Rs./ha	3,108	3,270	+162	ns
GRF[1]	Rs./ha	54,273	68,386	+14,113	***

***, **, *: significant at $p < 0.001$, 0.01, and 0.05 level; ns = not significant; [1]GRF = gross return above fertilizer cost; Prices (in Rs./kg): Rice = 14.00; N = 11.40; P_2O_5 = 32.20; K_2O = 18.80.

Averaged over sites, NE tool-based recommendations improved rice yield by 1 t/ha over the farmers' practice. The increased yield in the NE treatment was achieved through a significantly higher application of N and better timing of fertilizer application. Fertilizer cost in the NE treatment was similar to the investment by the farmers. The gross return over fertilizer cost was significantly higher in the NE treatment (**Table 1**), suggesting significantly higher economic return across sites.

One of the major objectives of improved nutrient manage-

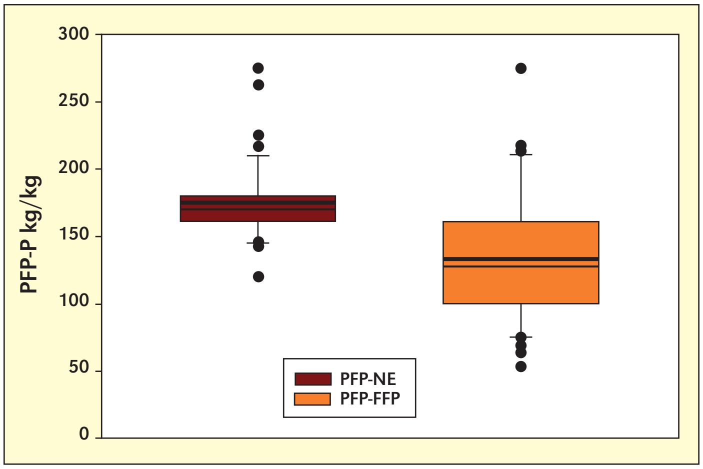

Figure 2. Average Partial Factor Productivity (PFP) for P in rice in the NE validation trials (n = 323) compared to farmers' fertilization practice (FFP) in West Bengal. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median and the thick line represents the mean. 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.

ment is to achieve high nutrient use efficiency at higher yield and farm profitability. The partial factor productivity (PFP) of P was used in this study to assess the efficiency of conversion of fertilizer or soil P to economic parts. The PFP is considered the most important index for on-farm studies, among the different indices of nutrient use efficiency, as it integrates the use efficiency of both indigenous and applied nutrients. The average partial factor productivity (PFP) of P in the NE treatment (175 kg grain/kg P_2O_5) was higher than the FFP treatment (134 kg grain/kg P_2O_5) across sites (**Figure 2**). The PFP of P in the FFP varied over a wide range (56 to 275 kg grain/kg P_2O_5) due to the wide variability in rice yield (3,400 to 6,200 kg/ha) and P application rates (16 to 90 kg/ha). The efficiency of P use was within a narrower range (125 to 275 kg grain/kg P_2O_5) in the NE treatment as the yield variability in the NE treatment was lower (**Figure 1**), P_2O_5 application (24 to 42 kg/ha) recommended by the NE tool was also within a narrow range than the farmers' practices.

The NE for rice validation trials in West Bengal showed that farmers' yield, profitability, and nutrient use efficiency in kharif season rice could be significantly improved by farmer- and site-specific fertilizer recommendations. Wide-scale dissemination of site-specific fertilizer recommendation has been a challenge due to lack of appropriate tools that can help extension agents develop such recommendations quickly. The NE tool is a significant innovation to fill that gap as was verified through the use of the tool by the extension mechanism of IKSL. The unique capability of the NE tool to develop site-specific recommendations in the absence of soil testing provides an opportunity to support the majority of rice farmers who do not have access to soil testing. BC-SA

Drs. Mandal and Shrotriya are with IKSL; Drs. Dutta, Majumdar, Satyanarayana, and Mrs. Govil are with IPNI South Asia Program; Dr. Pampolino is with IPNI Southeast Asia Program; Dr. Johnston is Vice President, and Asia & Africa Coordinator of IPNI.

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7th International Nitrogen Conference (INI 2016)

The Victorian Government and University of Melbourne are jointly hosting the 7th International Nitrogen Initiative Conference, at the Melbourne Cricket Ground, on December 4 to 8, 2016.

The theme of INI 2016 is **Solutions to Improve Nitrogen Use Efficiency for the World**. The program includes plenary presentations from many of the world's experts in the fields of nitrogen cycling and management, crop and animal production, emissions and environmental impacts with participation from research, industry and policy organizations globally. Further details of the conference are available at ini2016.com. BC

THE CALL FOR PAPERS IS NOW OPEN

Phosphorus Response of Oilseeds and Pulses in India and Profitability of Phosphorus Fertilizer Application

By K. Majumdar and V. Govil

Oilseed and pulse crops are critical to the food security scenario in India, with both showing strong responses to fertilizer P application.

Developing appropriate P management strategies involves an understanding of both crop responses to nutrient supply and crop P removal.

IPNI Image/K. Majumdar   Inset photo: IPNI Image/Ch. S. Rao

Castor crop being inspected by Dr. Majumdar. The inset photo shows severe P deficiency symptoms in a chickpea plant.

The importance of oilseeds and pulses in the Indian diet and economy is well documented. India is the world's largest producer of pulses. Besides providing the cheapest source of vegetable protein for human and animal nutrition, pulses play a significant role in sustainability of agriculture. Oilseeds occupy an important position in the agricultural economy of India. The country is also the largest producer of oilseeds in the world and contributes 7% of the global vegetable oils production, with a 14% share in the global oilseeds area (Jha et al., 2012). Oilseeds are major sources of fats and oil supplements in our diet. Oilseed meal, obtained after oil extraction, is used as an animal feed. They are a rich source of good quality proteins and can be utilized for production of value-added products like protein concentrate, baby food and biscuits after some processing.

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

India produced 18.3 million t (M t) of pulses and 30.9 M t of oilseeds with an annual productivity of 789 kg/ha and 1,168 kg/ha, respectively in the year 2012-13. The largest production of pulses and oilseeds in India has been recorded in Madhya Pradesh with production of 5.2 M t of pulses and 9.3 M t of oilseeds in 2012-13 (FAI, 2014).

Oilseeds area and output are concentrated in the central and southern parts of India, mainly in the states of Andhra Pradesh, Gujarat, Karnataka, Madhya Pradesh, Maharashtra,

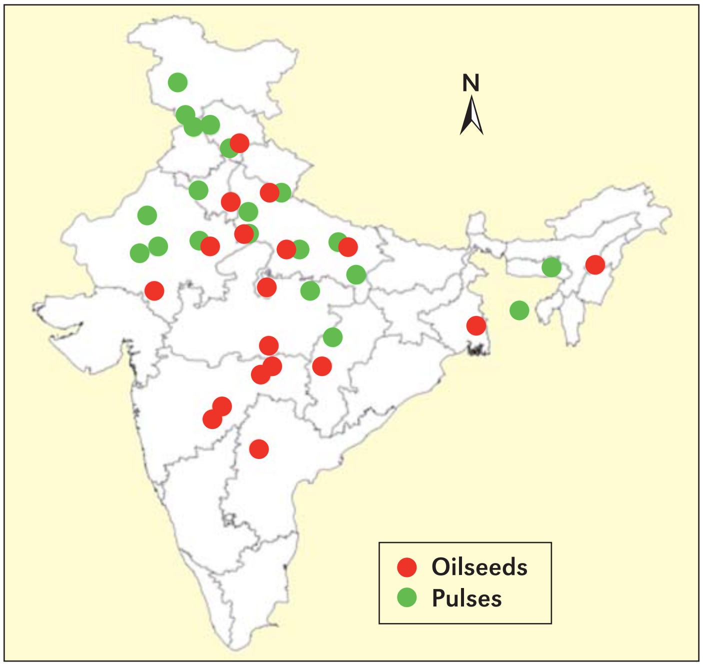

Figure 1. Location map of P response study sites in oilseeds and pulses.

and Rajasthan (FAI, 2014), while pulses are mainly grown in Andhra Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Uttar Pradesh (FAI, 2014).

India imports 2 to 3 M t of pulses every year to meet the growing demand. The projected pulse requirement for the year 2030 is 32 M t, which will require an annual production growth rate of 4.2% (Nadarajan et al., 2013). In case of edible oilseeds, the demand is projected to grow at 12.6% per year during 12th 5-year Plan (2012-2017), which is two and half times more than the growth rate experienced in the domestic production of oilseeds during the previous decade.

The major oilseeds produced in different areas of India are groundnut, mustard, rapeseed, soybean, sunflower, safflower, sesamum, niger, and castor whereas some major pulses are chickpea, pigeonpea, black gram, green gram, lentil, cowpea, horsegram, field pea, lathyrus and kidney bean. Phosphorus plays an important role in the growth and development, as well as maturity of all crops. An adequate supply of P in the early stages helps in initiating its reproductive parts. It hastens the maturity and improves the quality of seeds. In legumes, P plays a major role in the formation and effective fixation of N by plant nodulation. The P requirement of oilseeds and pulses is relatively high as it plays an important role in plant metabolism (Kubsad et al., 2008).

Pulses respond well to applied P in most of the Indian soil types. Since N is applied only to meet the initial vigour of the crop, and response to applied K in pulses is not encouraging, phosphorus application has become the base of fertilizing pulses in India. Pulses are energy rich crops and remove sizeable quantities of nutrients from the soil. Pulse crops require 9.2 kg (chickpea grain) to as high as 48.1 kg (greengram grain) P_2O_5 for producing one tonne of grain. In the case of oilseeds, uptake of P_2O_5 per tonne of economic produce ranges between 8.4 kg (safflower seed) to 30.9 kg for soybean (FAI, 2014). The share of major nutrients in the total uptake pattern of oilseeds is 48% N, 16% P_2O_5 and 37% K_2O. The higher requirement of phosphorus by oilseeds are well documented (Tandon, 2002).

It is estimated that 40.6 and 76.5% of the area under pulses and oilseeds are fertilized in India. The estimated application rate of P_2O_5 is 43.2 and 40.5 kg per hectare of area treated with fertilizer under pulses and oilseeds, respectively (FAI, 2014).

Considering the importance of P nutrition in oilseeds and pulses, the present review was conducted to assess the P responses in reported studies in four leading scientific journals of India namely, Journal of the Indian Society of Soil Science, Indian Journal of Agronomy, Indian Journal of Agricultural Sciences and Indian Journal of Fertilisers, over the period between 2003-2012. There were 87 reported studies on P responses in oilseeds, while 62 studies reported on P responses in pulses. The studies were well distributed across major pulse and oilseeds growing areas of the country, covering major soil types. The study locations are shown on the map of India (**Figure 1**), where each individual point represents multiple sites in the state. The reported studies for oilseeds were from Andhra Pradesh, Chhattisgarh, Delhi, Himachal Pradesh, Maharashtra, Nagaland, Rajasthan, Uttaranchal, Uttar Pradesh, and West Bengal. The studies on pulses were distributed over Chhattisgarh, Delhi, Haryana, Himachal Pradesh, J&K, Rajasthan, Uttaranchal, and Uttar Pradesh. The studies that reported the grain yield responses due to P were chosen for analysis, while the ones that reported the effect of P application on quality parameters like oil content were ignored.

The information on crop yield responses to applied P level was collated from the reviewed papers to estimate P yield response in oilseeds and pulses using the following equation:

P response = Yield of the crop at the applied P level (kg/ha) - Yield of the crop at no P application (kg/ha)

Current value of the crop commodities and cost of P fertilizer was used to estimate the return on investment (ROI) on P application to oilseeds and pulses (Jat et al., 2012):

ROI for P fertilizer = Yield increase due to P fertilizer (kg/ha) x minimum support price (MSP) of crop (Rs/kg) / Applied P_2O_5 (kg/ha) x cost of P_2O_5

Figure 2 shows the extent of P response in oilseeds and

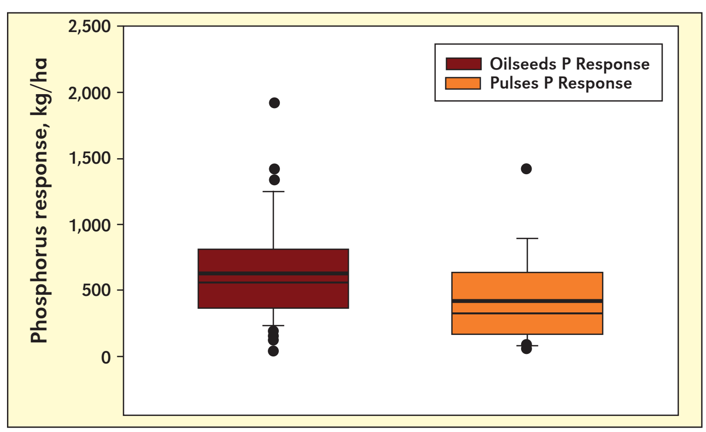

Figure 2. Range of grain yield response to P application in oilseeds and pulses. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median and the thick line represents the mean. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

Table 1. Distribution of reviewed data in yield response classes.

Yield response for P, kg/ha	Oilseeds: Number of samples (total = 87)	Oilseeds: % samples	Pulses: Number of samples (total = 62)	Pulses: % samples
<300	17	19.5	30	48.4
300-600	27	31.0	12	19.4
>600	43	49.4	20	32.3

pulses across the reviewed studies. Phosphorus response in oilseeds was higher than pulses. Average grain yield response of oilseeds averaged 700 kg/ha, while average P response in pulses was 400 kg/ha. The response range of the reviewed data was classified in three yield response classes (**Table 1**). In oilseeds, 19.5% of the studies showed P response of < 300 kg/ha, 31% showed a response of 300 to 600 kg/ha, while 49.4% of the studies showed greater than 600 kg/ha of grain response due to P application. In pulses, the majority of the studies (48.4%) showed P response of < 300 kg/ha, while 19.4% and 32.3% studies showed 300 to 600 kg/ha and > 600 kg/ha of yield response to P, respectively.

Subsequently, P response of individual crops (such as mustard or chickpea), within the broad groups of oilseeds and pulses, were grouped together and average yield response to P application for each crop was estimated. The average yield response in each crop and the average P application rates were used, along with MSP of crops and current cost of P fertilizer, to estimate the ROI on P fertilizer application. **Table 2** showed that P response in oilseeds range from 0.9 to 12 kg of grain per kg of applied P. The ROI on P in oilseeds was 0.8 to 10.4 Rs/Re on P. The results showed that ROI was reasonably high even at the perceived high cost of P fertilizer and generally low P response of oilseeds, showing that farmers can make significant profit from P application in oilseeds. Phosphorus response of pulses was lower than oilseeds, ranging from 1.9 to 11.5 kg per kg of P_2O_5 application (**Table 3**). The ROI on P application in pulses was between Rs.1.9 to 12.9 Rs/Re on P (**Table 3**).

Phosphorus application rates varied widely within and between crops in the surveyed literature. While calculating the ROIs (**Table 2 and 3**), the application rates in different experiments for an individual crop were averaged out to a common application rate. This has an inherent weakness of data redundancy, which might lead to inappropriate representation of ROI. Besides, such average application rates, combining different experimental data from varied locations, may not provide guidance to the user to achieve a particular yield response or ROI.

To avoid data redundancy, the P response data were classified in quartiles within the observed range of P responses in the reviewed literature. This is expected to help guide P application based on yield response and crop uptake. The first, median and third quartile of P responses in oilseeds and pulses were estimated and are given in **Table 4**. Return on investment was re-calculated based on the response levels in **Table 4** and at three chosen P application rates. The three P application rates were selected on the basis of current state recommended P application rates in pulses and oilseeds in different states of India (Tandon, 2002). In case of oilseeds, the range of application rates used were 30, 60 and 90 kg P_2O_5/ha, while 40, 60 and 80 kg P_2O_5 application rates were used for pulses for estimating ROI (**Table 5**). The application of 30 kg P_2O_5/ha in oilseeds gives an ROI of 10.7, 17.1 and 24.6 Rs/Re invested in P at the 370, 590 and 850 kg/ha P responses, respectively. Increasing application rates to 60 and 90 kg/ha in oilseeds decreases the ROI, and the lowest ROI of 3.6 was observed at 370 kg/ha response level and at 90 kg application rate. Similarly for pulses, ROI of 4.4, 9.1 and 17.7 Rs/Re were achieved at the 156, 325 and 633 kg/ha P response levels with application rate of 40 kg P_2O_5/ha. The economic return from P application in pulses is lower than oilseeds due to lower P responses evident in the reviewed literature.

Table 5 shows that applying P based on P response of oilseeds and pulses are economically viable at current cost of

Table 2. Yield response and net return on P fertilizer application in different oilseeds

Crop	P_2O_5 applied, kg/ha	Yield increase due to P_2O_5, kg/ha (±SE)	Net return due to P_2O_5, Rs./ha	Net return, Rs/Re invested on P_2O_5	Response per kg of P_2O_5 applied, kg/kg
Soybean (30)	101	633 (±60)	17,713	7.08	8.14
Pigeonpea (2)	79	605 (±15)	16,940	6.67	7.67
Groundnut (7)	64	401 (±55)	11,216	6.34	7.30
Mustard (32)	102	611 (±76)	17,098	5.69	6.54
Sunflower (2)	80	73 (±30)	2,044	0.79	0.91
Raya (4)	60	720 (±95)	20,160	10.43	12.00
Castor (4)	195	667 (±244)	18,676	2.96	3.40
Sesame (6)	158	1,180 (±18)	33,040	6.6	7.59

*Price of P: Rs.32/kg P_2O_5; Average minimum support price of oilseeds: Rs.28/kg of grain; numbers in parentheses represents the number of studies in a particular crop.

Table 3. Yield response and net return on P fertilizer application in different pulses

Crop	P_2O_5 applied, kg/ha	Yield increase due to P_2O_5, kg/ha (±SE)	Net return due to P_2O_5, Rs./ha	Net return, Rs/Re invested on P_2O_5	Response per kg of P_2O_5 applied, kg/kg
Blackgram (7)	90	106 (±20)	3,821	1.90	1.70
Gram (5)	147	445 (±91)	16,020	3.68	3.29
Greengram (6)	58	221 (±19)	7,956	4.91	4.39
Pigeonpea (9)	111	460 (±41)	16,572	5.09	4.55
Urdbean (5)	72	129 (±33)	4,658	2.09	1.87
Cowpea (1)	20	139	5,004	7.77	6.95
Chickpea (26)	68	640 (±60)	23,051	12.89	11.53
Mungbean (3)	59	127 (±3)	4,560	3.75	3.36

*Price of P: Rs.32/kg P_2O_5; Average minimum support price of pulses: Rs.36/kg of grain.

Table 4. Classes of P response in oilseeds and pulses.

	Yield Response for P, kg/ha	
	Oilseeds	Pulses
1st Quartile	370	156
Median	590	325
3rd Quartile	850	633

P. The generally low P response of oilseeds and pulses, because of achieved low yields in these crops and high cost of phosphate, makes it important that P fertilizer is applied based on a critical assessment of yield response. **Table 5** also poses the important question that at 850 kg/ha P response in oilseeds, how would a farmer decide the appropriate application rate? All the three P application rates, at 850 kg/ha P response, gives significant ROI in P. The highest return is always the most attractive for a farmer, but are there other considerations that need to be taken into account before choosing the appropriate rate? It seems that while deciding about the right P applicaton rate, one has to consider the uptake per tonne of economic produce. Phosphorus is usually accumulated in the grain of a crop, with very little amount of P stored in the aboveground biomass. In such a scenario, crops with comparatively higher uptake requirement to produce one tonne of grain (soybean, sesame, groundnut, etc.) should be treated with higher fertilizer rates than crops with lesser uptake requirement of P. In other words, P application rates should also be based on uptake requirement besides the expected response to P application to limit P mining from the soil. Soils showing higher P response suggests lower availability of P, such as red & lateritic soils, and a higher P application rate in a high P requiring crop in such a soil would ensure reasonably high return and maintainence of P fertility levels of the soil. Similar logic could be extended to other P response levels in **Table 5**, where more P should be applied to oilseeds or pulses that have high P uptake requirement even if the response levels are similar.

Summary

Improving oilseeds and pulses production in India is required to meet the growing demands. Area expansion is possible in these crops as the relative prices with competing crops are favorable and the relative profitability is higher. Crop intensification in underutilized farming situations like rice fallows can contribute to an increase in area under oilseeds and pulses. However, there are ample opportunities to improve productivity of these crops from the existing area through proper nutrient management. This will lead to sustainable intensification, without sacrificing the area under other crops, while meeting the national requirement. BC-SA

Table 5. Return on Investment (ROI) on P fertilizer in oilseeds and pulses at different crop response levels and application rates.

Yield response classes of Oilseeds, kg/ha	370	590	850
	Return on Investment (Rs/Re) in oilseeds#		
At 30 kg P_2O_5/ha application rate*	10.7	17.1	24.6
At 60 kg P_2O_5/ha application rate	5.4	8.6	12.3
At 90 kg P_2O_5/ha application rate	3.6	5.7	8.2
Yield response classes of Pulses, kg/ha	156	325	633
	Return on Investment (Rs/Re) in pulses@		
At 40 kg P_2O_5/ha application rate	4.4	9.1	17.7
At 60 kg P_2O_5/ha application rate	2.9	6.1	11.8
At 80 kg P_2O_5/ha application rate	2.2	4.5	8.8

*Price of P: Rs.32/kg P_2O_5; #Average minimum support price of oilseeds: Rs.28/kg grain; @Average MSP of pulses: Rs.36/kg of grain

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

By Y.R. Aladakatti, D.P. Biradar, D. Shivamurthy, T. Satyanarayana, K. Majumdar, S. Dutta, and A.M. Johnston

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.

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

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 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-P_2O_5-K_2O kg/ha for maize and 150-110-100 kg/ha for wheat), ii) P omission (250-0-120 N-P_2O_5-K_2O kg/ha for maize and 150-0-100 kg/ha for wheat), iii) Site-Specific Nutrient Management (SSNM) (200-90-100 N-P_2O_5-K_2O kg/ha for maize and 120-60-50 kg/ha for wheat) and iv) Farmers' Fertilization Practice (FFP) (115-52-45 N-P_2O_5-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

Acknowledgement

The authors greatly appreciate and acknowledge the financial and technical support of IPNI management and the Coordinators of Global Maize Work Group of IPNI for this study.

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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

Comparative Study on Yield Variability and Phosphorus Fertilizer Use Trends in the Established and Emerging Maize-growing Districts of Telangana

By A. Madhavi, D. Balaguruvaiah, M. Shankariah, G. Manjulatha, G. Kiran Reddy, Prabhakar Reddy, Pavanchandra Reddy, A. Srinivas, K. Suresh, T. Satyanarayana, S. Dutta, and K. Majumdar

Maize is an important cereal crop grown in 8 out of 10 districts in the newly formed state of Telangana, with surveys identifying yields ranging from 2.9 to 7.4 t/ha.

The yield trends and P fertilizer use by farmers were found to be correlated to socio-economic determinants of the farmers in the study area, suggesting the need for integrating farmers' socio-economic factors, along with bio-physical characteristics of farms, while designing intervention strategies to rationalize fertilizer use in maize.

Agriculture is one of the major important sectors contributing to the economy of the new state of Telangana. The state has about 5.7 million (M) ha cropped area under food and non-food crops. Maize is grown in 8 out of the 10 districts of the state, with an area of 0.64 M ha, occupying 11.3% of the total cropped area (Telangana statistics, 2013). The large poultry-farming sector in Telangana and adjacent states are the major consumers of maize grain, with the poultry feed assured market in this sector contributing to the increase in cultivated area under maize. The state produces 2.6 M t of maize grain with a productivity of 4.6 t/ha (**Table 1**), which is 80% higher than the national maize productivity (FAI statistics, 2014). Maize is considered both as an established and emerging crop in the state with respect to the expansion of area under maize owing to its higher yield potential and its adaptability to multiple seasons under different ecologies.

Table 1. Area, Production and Productivity of maize in Telangana.

District	Area, ha	Production, t	Productivity, kg/ha
Adilabad	22,020	68,773	3,123
Karimnagar	108,706	568,675	5,231
Khammam	32,057	172,456	5,380
Mahabubnagar	118,589	55,000	4,729
Medak	142,205	643,031	4,522
Nizamabad	94,834	505,743	5,333
Ranga Reddy	42,971	166,701	3,879
Warangal	80,092	387,607	4,840
Total	641,474	2,567,986	4,630

Source: (http://www.telangana.gov.in)

Fertilizer nutrient use in Telangana during 2013-14 was 1.34 M t, of which N, P_2O_5 and K_2O use accounted for 73, 21 and 6%, respectively (FAI, 2014). The nutrient use in southern India indicated a wide range of P_2O_5 application (38 to 230 kg/ha) in maize. An earlier study by Satyanarayana et al. (2012) suggested that farmers' perception-based fertilizer application often exceeds economic rates of P_2O_5 application. The authors attributed such inappropriate application of P_2O_5 to lack of awareness among maize growers about appropriate fertilization in hybrid maize in general, and about P requirement of maize in particular. Generally, farmers use complexes as the sources of P fertilizer, applied both at the time of planting and through top dressing at various stages of crop growth. As a result, P is applied throughout the growing season without knowing the crop's demand, or the right time of P application, that leads to uneconomical use of P fertilizer by farmers. Jat et al. (2012) reported an average maize yield response of 853 kg/ha in omission plot studies, and a ROI of 2 Rs/Re even with ample application rates of P in the trials, indicating the importance of P application in maize. The socio-economic determinants of farmers often significantly influence their fertilizer application decisions (Banerjee et al., 2014), leading to variation in farmers' yields. So improved fertilizer decision support in maize must integrate both biophysical characteristics of farms and socio-economic factors of farmers to achieve the twin goals of improved productivity and improved farm profitability in smallholder systems of maize cultivation. The current study investigates the P fertilizer use by farmers in maize and their associated socio-economic factors in determining the maize yield variability of the state.

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

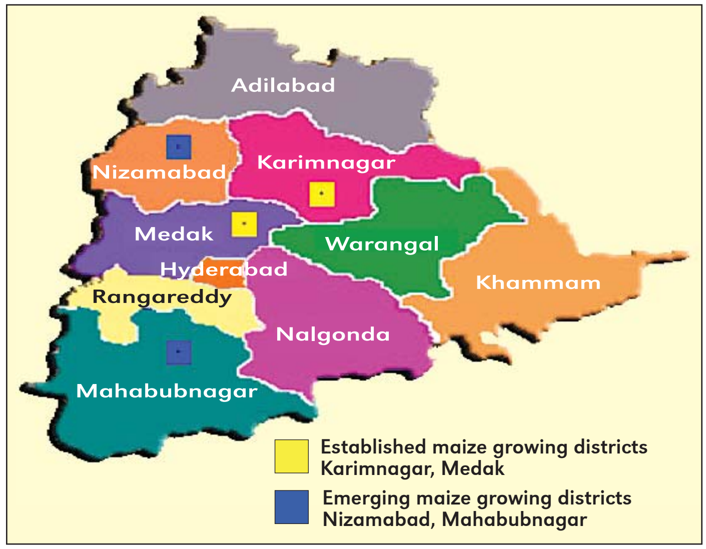

Figure 1. Collaborative project study area in Telangana state.

A joint collaboration was established between Professor Jayashankar Telangana State Agricultural University (PJTSAU) and International Plant Nutrition Institute (IPNI) to initiate a study on agronomic, economic, social and environmental

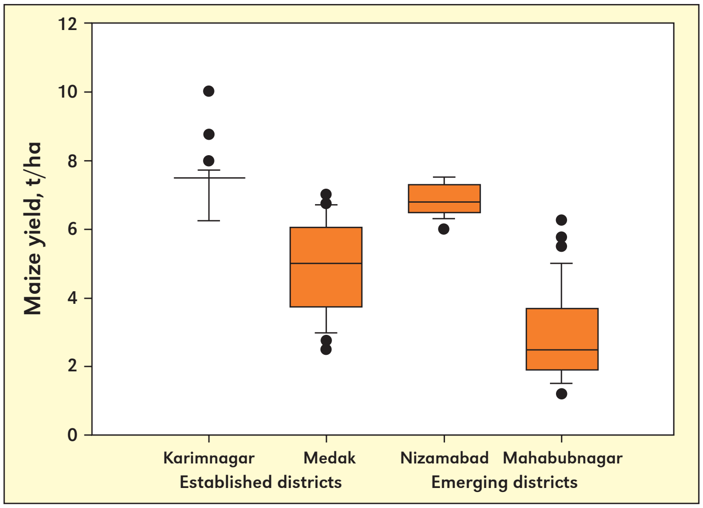

Figure 2. Yield variability in the established and emerging maize-growing districts of Telangana. Boxes represent data within the first and third quartiles (interquartile range). The line inside the box denotes the mean. Lines extending beyond the interquartile range denotes the 10^{th} to 90^{th} percentiles of the data. Statistical outliers are plotted as individual points outside these lines.

benefits of improved nutrient management practices in maize production systems under variable farm size, climate, soil fertility conditions and farmer resource endowment in Telangana. This paper considers a part of the study, which discusses the maize yield variability and P fertilizer use trends in four districts of Telangana and its associated relationship with different socio-economic aspects of farmers.

A rapid rural survey, to assess socio-economic and biophysical aspects of farmers, was conducted in four maize-growing districts of Telangana. Based on the criteria of area under maize cultivation, prevailing yield levels, and access to water while growing crops (irrigated or rainfed situations), two established and two emerging maize growing districts were selected. Of the eight major maize-growing districts in Telangana (**Table 1**), Karimnagar and Medak are chosen as the established districts while Nizamabad and Mahabubnagar are considered as the emerging districts (**Figure 1**). Karimnagar and Nizamabad falls under northern Telangana zone, with red earth soil type having a mix of loamy soils (Chalkas) and black cotton soils and with an annual rainfall of 900 to 1,150 mm. Medak district comes under central Telangana zone while Mahabubnagar is in southern Telangana zone with normal rainfall of 800 to 1,150 and 500 to 670 mm, respectively. The soil type in Medak was red earths with loamy texture (chalkas), red sandy soils and black cotton soils in pockets whereas the soil type in Mahabubnagar was predominantly red soils with chalkas.

Three villages in each of the selected districts were chosen in consultation with the experts from the agricultural university and staff of the department of agriculture. Villages with high maize acreage under the identified maize-growing seasons were selected for the survey. A total of 15 maize farmers in the villages were then selected for a detailed survey through systematic sampling. The number of maize farmers in each village (n) was divided by fifteen (n/15 = k), where k represented the frequency of sampling or the number of households between surveyed households. The farmers in each village were interviewed on socio-economic profile, farm profile, farm asset inventory, crop management practices, maize production related problems, soil resource use, and water resource use. From the survey, information on maize yield variability and the extent of P fertilizer use were determined in addition to identifying the major socio-economic factors responsible for higher maize yields in the study region.

Maize Yield Variability in Telangana

The survey indicated high maize yield variability among farmers in the established and emerging maize-growing districts of Telangana (**Figure 2**). In the established maize-growing districts, grain yield varied from 6.25 to 10 t/ha with a mean yield of 7.4 t/ha in Karimnagar. In Medak district, the grain yield ranged from 2.5 to 7.0 t/ha with an average yield of 4.91 t/ha. The higher yield in Karimnagar may be attributed to a high average rainfall (1,025 mm) as compared to 975 mm in Medak district. Also, the rainfall productivity (kg yield per mm of rainfall) of Karimnagar (7.2) is higher than Medak (5.0), and all the surveyed farmers in Karimnagar have access to deep bore well and farm ponds, whereas, only 46% of farmers in Medak district have access to bore well as an alternative source of irrigation to maize crop. From the survey, it was revealed that an average maize farmer in Karimnagar practicing farming for 23 years have the experience of growing maize for almost the same period (average of 21.5 years). In Medak, even though most of the farmers have farming experience of more than 23 years, they have the experience of growing maize only for the last 10 years (**Figure 3**). The longer experience of Karimnagar farmers may have helped them fine tune agronomic practices that attributed to higher maize yield over the farmers in Medak district.

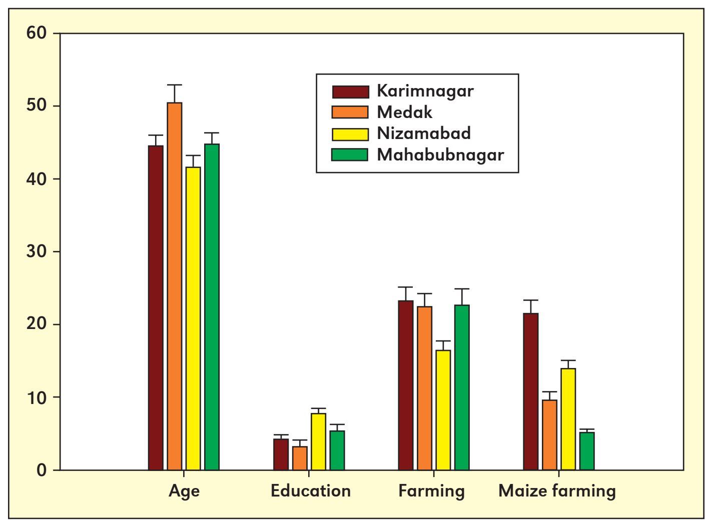

Figure 3. Characteristics of maize-growing farmers in Telangana. Age, farming and maize farming are in years and education is shown as grade level.

In the emerging maize-growing districts of Telangana, maize yield in Nizamabad averaged 6.83 t/ha and ranged from 6.0 to 7.5 t/ha, indicating a narrow variability among the maize-growing farmers in the district (**Figure 2**). Maize yield in Mahabubnagar averaged 2.91 t/ha and ranged from 1.2 to 6.25 t/ha, registering the lowest maize yield among the four districts considered under the study. The survey indicated that the respondent farmers have the experience of growing maize

Table 2. Fertilizer nutrient use (kg/ha) trends in maize growing districts of Telangana.

	---- N ----		---- P_2O_5 ----		---- K_2O ----		
District	Range	Mean	Range	Mean	Range	Mean	Total
Karimnagar	80-286	201	0-150	76	30-300	127	404
Medak	140-488	228	75-473	131	0-150	42.5	402
Nizamabad	208-260	234	64-80	73	32-40	36	343
Mahabubnagar	75-620	207	0-230	100	0-30	0.7	308

only during the last five years even though they have been growing crops over the last 23 years (**Figure 3**). The survey also indicated that farmers in this district grow maize only during kharif season, completely dependent on rainfall, and keeping the land fallow during the rest of the year. Mahabubnagar is the second largest district in Telangana growing maize next to Medak (**Table 1**) and based on the survey data, it was observed that farmers have the experience of growing maize in the last five years even though they have the farming experience of more than 20 years (**Figure 3**). From this observation, it may be inferred that the majority of area expansion under maize has happened in the recent past indicating maize as the potential option of crop diversification during the kharif season where crop is grown predominantly under the rainfed situations.

Fertilizer Use Trends in Telangana

Data in **Table 2** and **Figure 4** showed the fertilizer use trends in the surveyed region. **Table 2** indicated that the total nutrient use ($N+P_2O_5+K_2O$) in the maize-growing districts of Telangana was highest in Karimnagar (404 kg/ha), followed by Medak (402 kg/ha), Nizamabad (343 kg/ha) and Mahabubnagar (308 kg/ha). Whereas, the partial factory productivity, an indicator of productivity of maize crop in comparison to its nutrient input, was highest in Nizamabad (19.9) followed by Karimnagar (18.3), Medak (12.2) and Mahabubnagar (9.4), respectively. This gives an indication that farmers in Nizamabad and Karimnagar followed a generally better fertilizer application strategy, which is probably associated with the experience of maize farming. Farmers in Karimnagar growing maize during the last 22 years had a better understanding of the importance of K response in maize and thus applied adequate K_2O rates to an extent of 127 kg/ha (**Figure 4**). Similarly, farmers of Nizamabad, owing to higher education (average of Grade 8) and long experience of maize farming (average of 14 years), understood the importance of balanced fertilization and restricted the nutrient use to a narrow range of 208 to 260, 64 to 80 and 32 to 40 kg/ha of N, P_2O_5 and K_2O, respectively (**Table 2**). Maize-growing farmers in Medak and Mahabubnagar district applied imbalanced rates of N (140 to 488 and 75 to 620 kg/ha, respectively) and P_2O_5 (75 to 473 and 0 to 230 kg/ha, respectively) and neglected the application of K_2O (0 to 150 and 0 to 30 kg/ha, respectively), which resulted in unbalanced application of nutrients and led to lower maize productivity of 4.91 and 2.91 t/ha (**Figure 2**), respectively.

Figure 4 also illustrated that the P fertilizer use was 19, 33, 21, and 32% over the total nutrient use in Karimnagar, Medak, Nizamabad, and Mahabubnagar districts, respectively. The higher P_2O_5 use in Medak and Mahabubnagar districts was found to be due to top dressing of P through the use of complex fertilizer sources. This indicated that farmers in this region

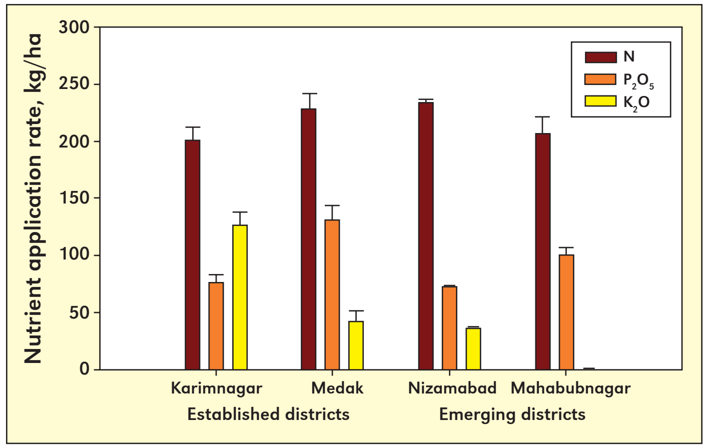

Figure 4. Fertilizer (N, P_2O_5, K_2O) use trends in maize-growing districts of Telangana.

were not aware of the right timing of P fertilizer use in maize. The above discussion indicates a lack of awareness about the 4R principles among the maize-growing farmers in Medak and Mahabubnagar districts, which provides opportunities for improving nutrient management in maize through 4R education.

Relationship between Maize Yield and the Socio-economic Aspects of Farmers

In Karimnagar, the yield of maize was significantly and positively correlated with the age of farmers and farm income, whereas, negatively and significantly correlated with the non-farm income (**Table 3**). This probably confirms that experience of farmers and investment from farm income helps maize yields in Karimnagar. Negative correlation between maize yield and non-farm income suggests that farm families more dependent on non-farm income probably put lesser attention to agronomic practices, adversely affecting maize yields. However, maize grain yield was negatively and significantly correlated with the age of the farmers in Nizamabad and Mahabubnagar. The average age of farmers in Nizamabad was 41 (ranged from 24 to 70) and the average yield of maize (**Figure 2**) was the second largest (6.8 t/ha, next to Karimnagar) among the surveyed districts. This indicated that the young farmers in the district contributed to higher maize yield in Nizamabad, which was categorized as the emerging maize-growing district. In Mahabubnagar, the average age of the farmer was 45 and the average maize yield was 2.9 t/ha. The negative correlation between yield and farmer age probably indicated that the older farmers were associated with maize growing and there is a need to encourage young farmers to become involved in farming for improving the productivity of maize in Mahabubnagar.

In Nizamabad, farm income, total income and farm size were negatively and significantly correlated with maize yield (**Table 3**). This indicated that the small farmers with low farm or total income produced higher maize yields, whereas big farmers with high income obtained lower maize yields. This trend suggested that achieving high maize yields is a top priority for small farmers for their sustenance, and interventions should aim at efficient utilization of available resources to maintain high, profitable maize yield. Bigger farmers with higher incomes have opportunities to improve maize yield through higher investment and better yield targeting. In Karimnagar and Mahabubnagar, farmer's income was positively and significantly correlated with maize yield suggesting higher investment in maize production (**Table 3**). The negative and significant correlation between the P fertilizer use and years of farming in Medak and Mahabubnagar indicated that farmers applied higher doses of P, most likely due to P use throughout the cropping season, as a result of less experience in maize farming. Interventions to improve awareness among the farmers about 4Rs of P fertilizer use in the maize-growing districts of Medak and Mahabubnagar may improve farm profitability.

Summary

The above study helped in understanding the maize yield variability and the fertilizer use trends in the two established and the two emerging maize-growing districts of Telangana. The relationship between the maize yield and the socio-economic aspects of farmers was also well established. We believe that there are opportunities to rationalize fertilizer recommendations based on 4R principles and farmer socio-economics to improve the productivity and profitability of maize production in the newly formed state of Telangana. BC-SA

Acknowledgement

The authors greatly appreciate and acknowledge the financial support of CGIAR Research Program on Maize (CRP-Maize) for this study.

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Scientists of IPNI, CIMMYT and PJTSAU interacting with the farmers during a survey in Nizamabad district of Telangana.

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Table 3. Relationship of maize yield and P fertilizer use with different socio-economic factors of farmers in maize growing districts of Telangana.

District	Parameter	Relationship	Age	Education	Years of farming	Farm income	Non-farm income	Total income	Farm size
Karimnagar	Maize yield	r value	0.276	-0.281	ns	0.759	-0.637	ns	ns
		p-value	0.055	0.026		0.04	0.07		
	P_2O_5	r value	ns	ns	ns	ns	ns	0.167	ns
		p-value						0.027	
Medak	Maize yield	r value	ns	0.305	ns	ns	ns	ns	0.431
		p-value		0.01					0.017
	P_2O_5	r value	ns	0.357	-0.381	ns	ns	ns	0.347
		p-value		0.05	0.03				0.05
Nizamabad	Maize yield	r value	-0.776	ns	ns	-0.583	ns	-0.693	-0.841
		p-value	0.04			0.04		0.04	0.03
	P_2O_5	r value	-0.771	ns	-0.495	0.495	-0.261	-0.731	ns
		p-value	0.04		0.01	0.01	0.03	0.05	
Mahabubnagar	Maize yield	r value	-0.299	ns	ns	0.377	0.347	0.368	0.249
		p-value	0.045			0.01	0.01	0.012	0.013
	P_2O_5	r value	ns	ns	-0.249	ns	ns	ns	ns
		p-value			0.05				

The pair (s) of variables with positive correlation coefficients and *p* values below 0.05 tend to increase together. For the pairs with negative correlation coefficients and *p* values below 0.05, one variable tends to decrease while the other increases. For pairs with *p* values greater than 0.05, there is no significant relationship between the two variables. ns indicate non-significant.

Phosphorus Response in Bt Cotton: A Comparative Study in Karnataka and Odisha

By Y.R. Aladakatti, S.K. Pattanayak, T. Satyanarayana, D.P. Biradar, S.B. Manjunath, K. Majumdar and A.M. Johnston

A comparative study on the contribution of P to Bt cotton yield showed a high P response to seed cotton yield in Odisha over Karnataka by an extent of 920 kg/ha.

The study suggested a judicious P management strategy while growing Bt cotton in medium black to deep black soils of Karnataka, whereas adequate P application based on P response from ample NPK was recommended in the red and lateritic soils of Odisha.

Bt-cotton was the first GM technology to be introduced into India. The area under cotton has increased to 12.2 million (M) ha in 2011, an increase of about 4.5 M ha since the introduction of Bt-cotton in 2002. India is second only to China in global cotton production, which was increased significantly from 15.2 M bales during 2002 to 35.3 M bales during 2011. During this period, the productivity of lint in India has increased from 302 to 492 kg/ha (CICR, 2011). However, India is currently witnessing yield stagnation at 510 ± 27 kg/ha lint over the past 7 years from 2005 to 2011. Some of the reasons for yield stagnation in Bt cotton are: current hybrids not suitable for rainfed growing situations, prevalence of severe moisture stress during the critical period of peak boll formation stage, especially in regions with shallow and marginal soils, and imbalanced use of nutrients (Kranthi, 2012).

With the development of Bt technology, the transgenic traits increased crop yields due to reduced insect pest damage, which in turn resulted in more removal of nutrients into seed cotton from the soil system. The expression of the Bt protein in cotton was found to be reduced by nutrient deficiency in the crop, owing to restricted growth and poor crop health (Rochester, 2006). Nutrient management in cotton is a complex phenomenon due to its long duration (180 to 200 days for most of the Bt hybrids), and indeterminate growth habit, where simultaneous production of vegetative and reproductive structures during the active growth phase takes place (Ravikiran et al. 2012). Thus, a sound nutrient management strategy would be required that minimizes deficiencies and optimize nutrition for better crop yields.

Phosphorus is an important nutrient in cotton production. It is essential for vigorous root and shoot growth, promotes early boll development, hastens maturity, helps to overcome the effects of compaction, increases water use efficiency, and is necessary for energy storage and transfer in plants (Snyder and Stewart, 2003). The total P uptake in cotton is completed by the time the crop reaches the 50% open boll stage. Adequate P nutrition has to be supplied to build and maintain adequate soil P levels to ensure proper seed and lint development. Deshpande et al (2014) reported that the P availability in soil increased with advancement in crop age in Bt cotton compared to non-Bt cotton, indicating that the residual effect of P was more pronounced in soils grown with Bt cotton hybrids than the non-Bt cotton hybrids. Since India is leading in Bt cotton acreage, at an adoption rate of 92%, a study was proposed in the major Bt cotton growing areas of the country to understand the extent of P response in different cotton growing ecologies with the objective of understanding the contribution of P to maximize the yields of Bt cotton. This paper discusses the results of P response observed in the states of Karnataka and Odisha.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Ca – calcium; Mg = magnesium; B = boron; Cl- = chloride; Fe = iron; Zn = zinc; GM = genetically modified; DAS = days after seeding; One Bale = 170 kg.

P Omission Plot Studies in Karnataka

Three sets of experiments from Karnataka, conducted during the kharif season of 2012, were considered in this study. This included a replicated on-station experiment at the agricultural research station, Dharwad farm, one non-replicated on-station experiment at the main agricultural research station of the University of Agricultural Sciences, Dharwad, and 22 on-farm non-replicated experiments. The on-farm trials were distributed in the major cotton-growing districts of Dharwad, Gadag, Bijapur, Haveri, Belgaum, and Bagalkot, with varying soil types ranging from medium black to deep black soils of the order Vertisols. The details of soil properties at all the experimental sites are given in **Table 1**, which revealed that soil reaction was slightly alkaline in nature, the EC measured in 1:2.5 soil:water suspension was non-saline (≤ 0.4 dS/m), available N, P_2O_5 and K_2O contents were low (< 280 kg/ha), medium (22.5 to 55 kg/ha) and high (> 335 kg/ha), respectively (**Table 1**). Before the start of the experiment, the targeted seed

Table 1. Available nutrient status of the experimental locations.

Soil property	On-farm locations Range	Mean	S.D.	On-station locations ARS, Dharwad	MARS, Dharwad
pH	7.6-8.9	8.2	0.38	7.8	7.4
EC, dS/m	0.18-0.38	0.24	0.05	0.34	0.4
Available N, kg/ha	168-290	240	43.03	163.1	208
Available P_2O_5, kg/ha	35-85	44.3	11.4	52.2	35
Available K_2O, kg/ha	365-811	552.4	109.3	362.2	350
Available S, kg/ha	-	-	-	18.5	25
Available Ca, me/100g	-	-	-	40.0	4
Available Mg, me/100g	-	-	-	13.7	36
Available Zn, mg/kg	0.43-0.82	0.64	0.13	0.85	1
Available Fe, mg/kg	0.42-0.81	0.62	0.10	0.90	3

cotton yield was set at 3 t/ha considering the available information on attainable yields, nutrient uptake and soil test values from the experimental sites. At the on-station site, the experiment at ARS Dharwad farm was set up in a randomized block design with 4 treatments and 5 replications, whereas, at on-station site in MARS Dharwad and at the on-farm sites, 4 treatments were compared at each site, considering each location as an individual replication. The treatments consisted of ample NPK (180, 70 and 80 kg/ha N, P_2O_5 and K_2O) and three nutrient omission plots for N, P and K based on the ample NPK treatment where all limiting nutrients were applied in ample quantity except the omitted nutrient. Deficient micro and secondary nutrients were applied to all four treatment plots wherever necessary based on soil test results. Each treatment was laid out in a minimum plot size of one guntha (10 m x 10 m) covering an area of 4 gunthas at each location. Chiranjeevi and RCH-2 were the Bt cotton hybrids used at ARS and MARS farms, whereas, 7 different Bt cotton hybrids (Kanaka, Mallika, Shalimar, Brent Bt, RCH-2, Chiranjeevi, and JK Durga) were used at the on-farm sites. Urea, single superphosphate, KCl, and sulfates of Zn, Fe, Mg were the sources of nutrients used in the experiments and all nutrients were applied at sowing with the exception of N and K, which were applied in three splits (i.e., 25% basally, 50% at 30 DAS, and 25% at 60 DAS). Uniform cultural practices and plant protection measures were adopted in all treatments. The observations on growth and yield parameters were recorded at all the locations and the average of all on-farm sites were reported in addition to reporting the results of on-station sites separately.

Inferior growth of Bt cotton in red and lateritic soils of Odisha under P omission plot compared to better growth in K omission plot.

On-farm Trials with P Omission at Kalahandi, Odisha

Nine non-replicated on-farm trials were conducted during 2012 in Tol Brahamani, Chinpadar, and Ghantmal villages in Kalahandi district of Odisha state. The soils from the farmer fields were analyzed for physical and chemical properties before imposing the treatments. All soils were acidic (pH range 5.4 to 5.5) with low organic carbon (range 3.8 to 4.1 g/kg), low available N (127 kg/ha), medium available P_2O_5 (48 kg/ha, Bray-1 method), medium available K_2O (202 kg/ha), low S (8.1 kg/ha), and low in available B and Zn.

Five treatments were compared, which consisted of ample NPK (180 kg N, 85 kg P_2O_5, 115 kg K_2O, 55 kg S, 10 kg B through Borax, and 25 kg Zn through $ZnSO_4$), three nutrient omission plots for N, P and K, as described in the previous section, and farmer fertilizer practice (FFP). The average use of fertilizer by farmers of the locality was 160 kg/ha N, 100 kg/ha P_2O_5 and 60 kg/ha K_2O, while there was no application of any secondary and micronutrients by farmers. The compound fertilizer (20-20-0-13), along with Urea, SSP, MOP, Borax, and $ZnSO_4$ were the sources of nutrients used in the experiments and the application schedule was similar to that of Karnataka state. For this paper, the recorded observations on the growth and yield parameters were presented only for the Ample NPK and P Omission treatments and compared with FFP treatment.

Results

Seed Cotton Yield and P Response

The average Bt seed cotton yield in Karnataka due to ample NPK was 2,447 kg/ha (**Table 3**), with highest yield recorded at on-farm locations (3,600 kg/ha) followed by the on-station locations, 1,957 kg/ha at MARS Dharwad and 1,783 kg/ha at ARS, Dharwad farm. Earlier experiments conducted at on-station sites in Karnataka recorded similar yields of 1,706 kg/ha (Ravikiran et al., 2012) and 1,925 kg/ha (Hosamani et al., 2013) at agricultural college farm of Raichur with the application of nutrients at 125% of RDF (187.5, 93.5 and 93.5 kg/ha N, P_2O_5 and K_2O, respectively).

The higher yield at on-farm locations was in the ample NPK treatment, which had a significant effect on different growth parameters such as plant height, number of monopodials and sympodials, average boll weight and average seed cotton yield per plant (**Table 2**). Whereas, such effect of ample NPK treat-

Table 2. Growth and yield parameters of Bt cotton as influenced by P omission.

Treatments	Plant height, cm	No. of monopodia per plant	No. of sympodia per plant	No. of bolls per plant	Average boll weight, g	Seed cotton yield, g/plant
On-farm locations (n = 22), Karnataka						
Ample NPK	134.6	2.10	23.1	44.7	5.16	36.0*
N omission	104.1	1.89	19.3	29.1	4.30	20.3*
P omission	125.8	1.95	21.9	41.1	5.15	31.2*
K omission	125.7	2.01	21.8	40.5	5.12	29.7*
C.D. at 5%	7.1	0.11	0.65	1.88	0.15	0.66
On-station location, ARS Dharwad Farm						
Ample NPK	79.5	1.60	18.84	29.50	5.00	111.6
N omission	65.9	1.08	14.76	18.24	4.41	74.2
P omission	75.8	1.54	17.44	26.16	4.95	104.0
K omission	74.8	1.20	17.72	25.40	4.92	88.5
C.D. at 5%	8.5	NS	2.68	3.60	0.36	23.9
On-station location, MARS Dharwad						
Ample NPK	125.7	3.2	27.2	36.7	5.48	168.3
N omission	91.6	2.2	12.5	17.5	4.52	111.5
P omission	108.3	2.4	21.7	28.5	5.32	157.5
K omission	112.4	2.8	23.5	25.4	5.24	140.4
On-farm locations (n = 9), Odisha						
Ample NPK	157.1	-	-	20.65	13.7	31.74**
N omission	123.4	-	-	9.77	11.1	18.11**
P omission	128.6	-	-	16.94	11.8	18.67**
K omission	140.1	-	-	13.0	12.4	22.91**
FFP***	115.0	-	-	14.41	11.7	19.93**
C.D. at 5%	36.8			2.8	0.6	8.6

*At on-farm locations, seed cotton yield is reported as kg/guntha (100 m^2). **Data represents no. of squares per plant. ***Farmer Fertilizer Practice.

Table 3. Seed cotton yield and yield loss as influenced by omission of P.

Treatment	On-farm locations (Karnataka)		ARS, Hebbali farm		MARS, Dharwad		On-farm locations (Odisha)	
	Yield, kg/ha	Yield loss, %	Yield, kg/ha	Yield loss, %	Yield, kg/ha	Yield loss, %	Yield, kg/ha	Yield loss, %
Ample NPK	3,600	-	1,783	-	1,957	-	2,760	-
N omission	2,033	43.5	871	51.1	1,224	37.5	1,160	58.0
P omission	3,119	13.4	1,594	10.6	1,724	11.9	1,340	51.4
K omission	2,965	17.6	1,466	17.8	1,657	15.3	1,870	32.2
FFP*	-	-	-	-	-	-	1,180	57.2
C.D. at 5%	66.1	-	194	-	-	-	348	-

*Farmer Fertilizer Practice.

ment was non-significant with different growth parameters of Bt cotton at on-station locations, respectively (**Table 2**). The average yield due to P omission (2,146 kg/ha) also followed a similar trend, with highest yield recorded at on-farm locations (3,119 kg/ha) followed by the other two on-station sites (**Table 3**). The yield loss due to P omission at on-farm sites (13.4%) was statistically significant, whereas, the yield loss of 11% due to P omission at the on-station location was statistically non-significant.

In Odisha, nutrient application based on ample NPK treatment resulted in a significantly higher seed cotton yield (2,760 kg/ha), followed by P omission (1,340 kg/ha) and FFP (1,180 kg/ha). Omission of P led to a significant yield difference of 1,420 kg/ha as compared to the ample NPK treatment and resulted in a yield loss of 51.4%. The corresponding mean reduction in seed cotton yield in FFP over ample NPK was 1,580 kg/ha, which resulted in a yield loss of 57.2%. The higher yield in ample NPK over P omission and FFP is due to significant differences in growth parameters (**Table 2**), which revealed more number of bolls and more number of squares per plant in addition to recording a high average boll weight in ample NPK treatment.

The seed cotton yield response to application of P (**Figure 1**) across all the on-farm and on-station locations in Karnataka varied from 189 to 820 kg/ha with an average of 459 kg/ha. In an earlier study, Biradar et al. (2011) reported a low P response of 374 kg/ha in cotton grown at Dharwad and 293 kg/ha at Siruguppa and indicated a yield loss of 11 and 12% respectively due to omission of P. The low P response in Karnataka is ascribed to the soil type of the experimental sites with medium black to deep black soils having medium available P_2O_5 (average of 43.8 kg/ha across all the locations in the study as given in **Table 1**). The average post harvest available P_2O_5 in the P omission plot at on-farm locations was 30 kg/ha against an initial soil available P_2O_5 of 44 kg/ha, whereas, at an on-station site at Dharwad farm, the corresponding soil available P_2O_5 after harvest of cotton crop in P omission treatment was 36.9 kg/ha against an initial soil P_2O_5 level of 52.2 kg/ha (**Table 1**), respectively, indicating a retention of medium level of soil P even after harvest of Bt cotton. The increased P availability with advancement in crop age was also ascribed to increased root activity in the soil. Plant roots excrete organic acids and chelating organic compounds in rhizosphere, which form multiple complex compounds with

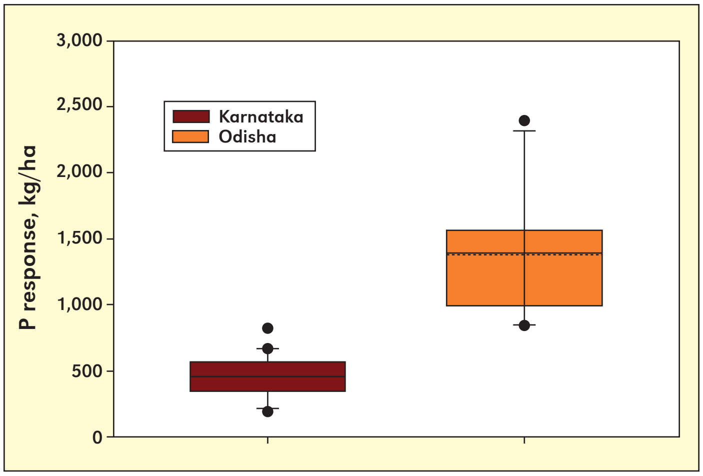

Figure 1. Range of seed cotton yield response to P application. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or media, and the dotted line denotes the mean. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

Ca, Mg and/or Fe and thereby increased P availability in soil (Tinker, 1980).

The seed cotton yield response to P application across nine on-farm locations in Odisha varied from 840 to 2,390 kg/ha, with an average of 1,420 kg/ha. The high P response in Odisha (**Figure 1**) was due to the red and lateritic soil type of the experimental sites with acidic soil pH (ranged from 5.4 to 5.5 across nine on-farm sites) and low available soil P_2O_5 (average of 27.4 kg/ha, Bray-1 method). Misra et al. (1989) reported a high P-fixing capacity (80 to 91%) in the soils of Odisha, which tends to reduce the efficiency of the added P fertilizer (Dev and Rattan, 1998). The study indicated a low response of Bt cotton to application of P in Karnataka, which is 32% of the P response in Odisha (**Figure 1**). The difference of P uptake between ample NPK treatment and P omission treatments in Karnataka and Odisha was 4.3 and 9.5 kg/ha (**Table 5**), indicating that the lower P response in Karnataka over Odisha is also due to low P uptake in Karnataka than in Odisha. Deshpande et al. (2014) reported a high available soil P residue after the harvest of Bt cotton due to low absorption of soil P by Bt cotton hybrids in Vertisols of Maharashtra.

Effect of P omission on the economics of Bt cotton at on-farm locations in Karnataka (**Table 4**) revealed that the gross returns, net returns and benefit:cost ratio significantly decreased due to P omission over ample NPK by Rs.19,273, Rs.13,772 and 0.26, respectively. The overall reduction in net returns due to P omission over ample NPK was 19%, indicating the importance of P application in the Bt cotton-growing soils of Karnataka.

The results of this study based on P response and economics due to P application indicated a judicious P management strategy in Karnataka where Bt cotton is grown under medium black to deep black soils. However in Odisha, considering the critical role played by P in maintaining the productivity of Bt cotton in red and lateritic soils, adequate P application rates based on the results of P response from ample NPK may be promoted to improve P use efficiency of soils by reducing P-fixing capacity of soils. BC-SA

Table 4. Effect of P omission on economics of Bt cotton at on-farm locations in Karnataka.

Treatment	Gross returns, Rs./ha	Net returns, Rs./ha	% Reduction in net return	B:C ratio
Ample NPK	144,036	74,036	-	2.05
N omission	81,309	21,309	71.2	1.17
P omission	124,763	60,264	18.6	1.79
K omission	118,636	54,336	26.6	1.70
C.D. at 5%	2,645	2,645	-	0.04

Table 5. Nutrient uptake of Bt cotton as influenced by P omission.

Treatment	N uptake, kg/ha	P uptake, kg/ha	K uptake, kg/ha
On-station location, ARS Dharwad farm, Karnataka			
Ample NPK	46.0	7.8	61.0
N omission	13.5	3.5	25.5
P omission	35.5	3.5	48.6
K omission	33.5	4.2	26.9
On-farm locations (n = 9), Odisha			
Ample NPK	115.4	17.1	106.8
N omission	46.3	7.5	53.6
P omission	47.2	7.6	59.5
K omission	75.1	11.8	79.3
FFP*	52.6	10.4	56.7
C.D. at 5%	20.0	2.01	15.1

*Farmer Fertilizer Practice.

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

By V.K. Singh, R.P. Mishra, B.S. Dwivedi, S.K. Singh, and K. Majumdar

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**).

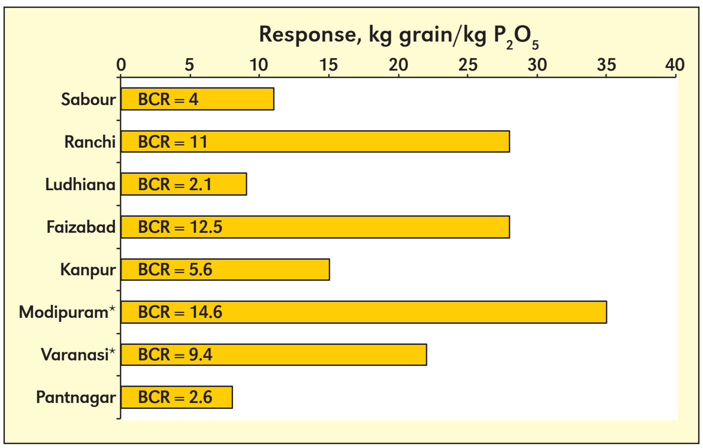

Figure 1. Response to P application in rice-wheat under site-specific nutrient management trials in the Indo Gangetic Plains. BCR = benefit to cost ratio.

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

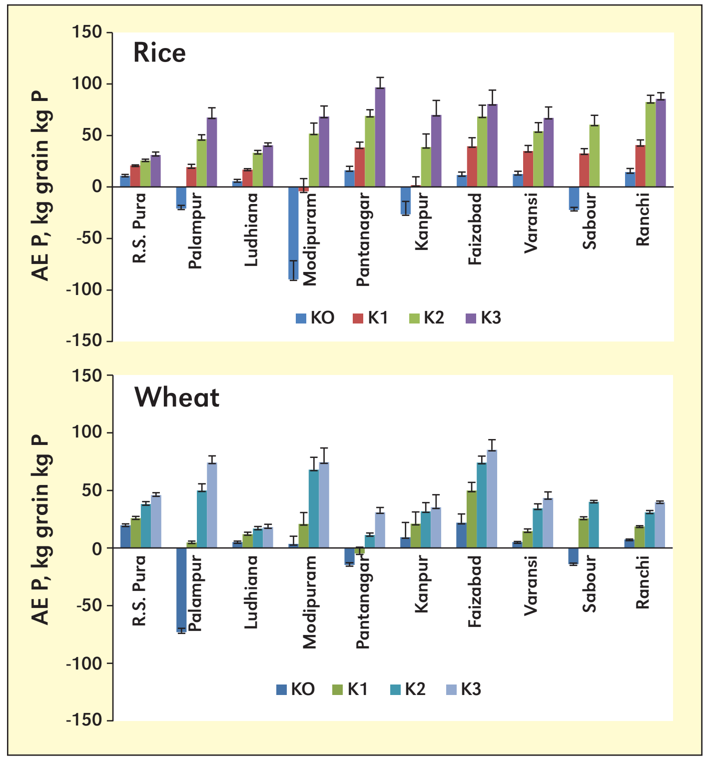

Figure 2. Agronomic efficiency (AE) P in rice and wheat as influenced by varying rates of K application (0, 33, 66, and 99 kg/ha K).

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.

	Agronomic efficiency of N, kg grain/kg N		Agronomic efficiency of P, kg grain/kg P		Recovery efficiency of N, %		Recovery efficiency of P, %	
Rates, kg/ha	Summer fellow	Summer cowpea	Summer fellow	Summer cowpea	Summer fellow	Summer cowpea	Summer fellow	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

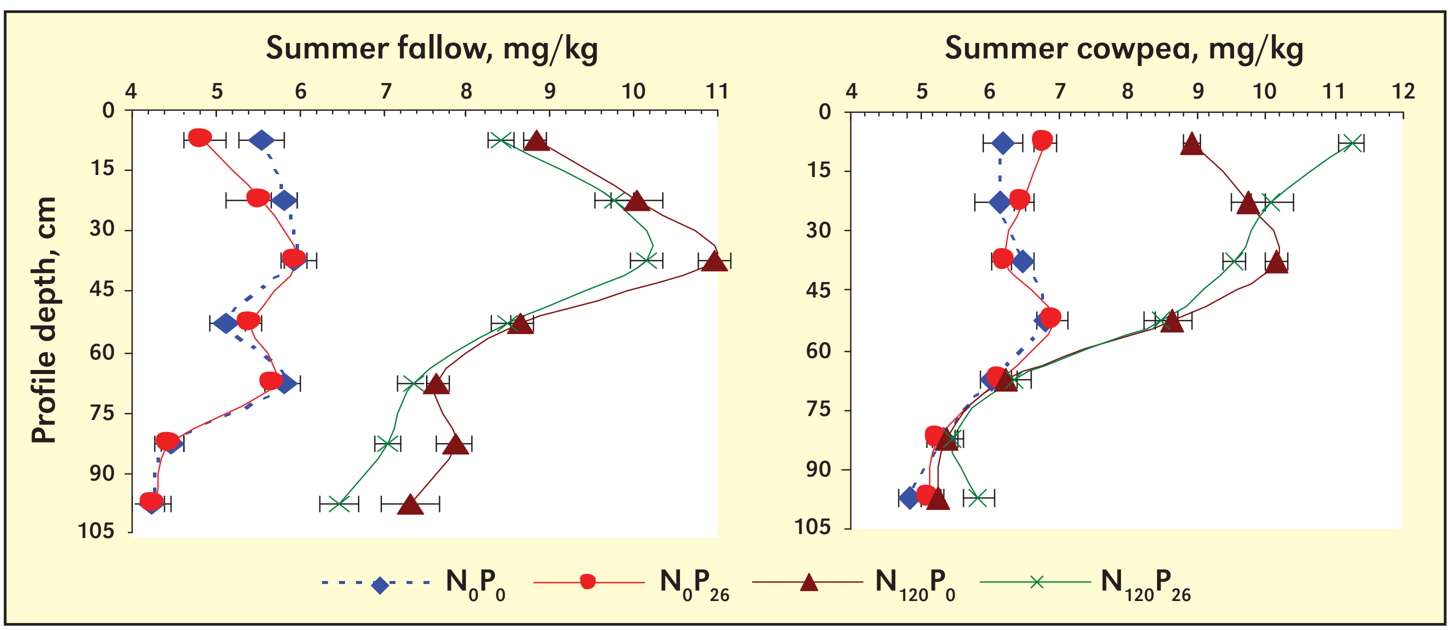

Figure 3. Effect of N P fertilization and cropping system on distribution of nitrate-N in soil profile under rice-wheat system.

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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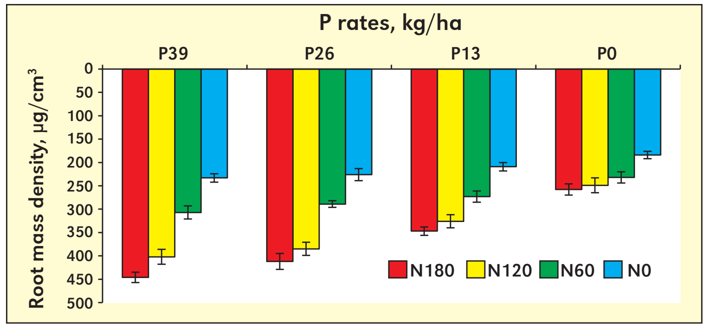

Figure 4. Effect of P application on root growth of wheat.

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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

S. Srinivasan, Tamil Nadu Agricultural University

Iron deficiency in cassava.

4R Phosphorus Management in Acid Soils of Odisha

By S.K. Pattanayak, T. Satyanarayana and K. Majumdar

Phosphorus nutrition for crops grown in Odisha is challenged by widespread soil acidity.

Applying 4R principles of P management offers opportunities for improved crop yields while alleviating the problems associated with low soil pH.

Soil acidity and poverty are synonymous in the state of Odisha where 80% of soils are acidic. Low water holding capacity, high bulk density, and soil crusting along with chemical constraints like low pH, low CEC, low base saturation (16 to 67%), high Al, Fe and Mn saturation, and high P-fixing capacity (80 to 91%) are major reasons for low crop productivity in such soils (Misra et al., 1989).

Phosphorus is one of the most limiting nutrient in the soils of Odisha owing to P fixation and immobile nature of P (Pattanayak et al., 2008). Acid soils fix two-to-three times more P per unit surface area than neutral or calcareous soil and the fixed P in acid soil is held with five times more bonding energy than calcareous soils. The extent of P fixation from the added P varies from 97% under air-dry condition to 76% under submerged condition, which is dependent on the type and quantity of clay minerals, sesquioxide and organic matter content (Pattanayak and Misra, 1989). Even though the soils of Odisha are low (27%) to high (73%) in soil available P, crops grown in Odisha exhibited a significant yield loss due to omission of P, which is 37% in hybrid rice (Pattanayak et al., 2008) and 49% in hybrid maize (Pattanayak et al., 2009). Thus, a proper P management strategy is required for improving and sustaining crop yields in the acid soils of Odisha.

The right source of P application in acid soils depends on the nature of growing environment. Under submerged soil conditions, owing to relatively less P fixation and high solubility of native P, application of readily available water-soluble sources of P fertilizers are more appropriate. Such water-soluble sources are, however, less efficient for upland red and lateritic soils due to high P fixation.

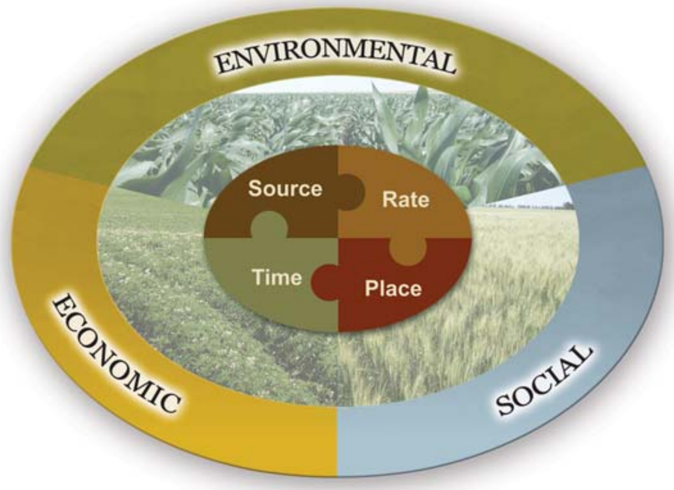
Pattanayak et al. (2011) reported that the unproductive/less productive acid upland soils (Alfisols, Inceptisols, and Entisols) can improve crop yields through application of the right nutrient rates based on soil testing, integrated with organic and inorganic soil ameliorants. P fertilizer applied at right time showed higher crop yields while improving the efficiency of applied P in the acidic soils of Odisha (Misra and Pattanayak, 1997). Similarly, Arnall (2014) reported that in acid soils with low pH conditions, right placement of P fertilizers through banding helps to alleviate the impact of Al toxicity as phosphate reacts with metals like Al and Mn to form insoluble compounds and reduces the harmful effects of the metals on the emerging seedling. Recognizing the benefits of 4R principles of P management, this paper discusses the importance of 4R strategies of P management in acid soils of Odisha.

Right Source of P Application

The efficiency of a P source varies depending upon the proportion of water-soluble P and soil properties (soil pH, P-fixing capacity, and organic matter content). In neutral to alkaline soils, materials containing water soluble P are generally more efficient than materials containing citric acid soluble or citric acid insoluble P. However, in very acidic soils, rock phosphate is as effective as water-soluble P sources for crops like rice (Singh and Singh, 2001). While managing acid soils, some forms of rock phosphate (RP) are known to be an appropriate economic source of P. However, RP sources available in India (Mussouriee RP, Udaipur RP, and Purulia RP) are relatively low grade and less reactive (Biswas et al., 2009) in nature. Use of such RP sources may result in low crop yields due to mismatch between crop uptake and P supply.

Mitra and Misra (1991) conducted a study in the red soils (Alfisol) of Semiliguda in Koraput district of Odisha where rice was grown in a soil with acidic pH (5.1 to 5.2) and low available P (Bray-1 P, 3 to 5 kg/ha). Four straight P sources were compared with two mixed sources of P at an application rate of 40 kg P/ha, and a common dose of N and K were applied to each treatment including control with P omission (**Table 1**). Results

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Al = aluminum; B = boron; Cu = copper; Fe = iron; Mn = manganese; CEC = cation exchange capacity; FYM = farmyard manure.



4R Nutrient Stewardship defines the right source, rate, time and place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem.

Table 1. Evaluation of P sources in rice grown in red soils of Koraput.

P source*	Grain yield, t/ha	Relative Agronomic Efficiency, %
Control (No-P)	2.4	-
SSP	3.0	100
MRP	2.8	58
MRP+SSP (3:1)	2.9	80
MRP+SSP (1:1)	3.1	113
Complex (20:20:0:13)	3.1	115
DAP	3.1	110
LSD (p = 0.05)	0.2	-

Source: Mitra and Misra (1991).
*SSP = single superphosphate, MRP = Mussouriee rock phosphate, DAP = diammonium phosphate.

Table 2. Evaluation of P application rates for hybrid rice grown in soils with acidic pH.

Treatment	Yield, t/ha	Nutrient uptake, kg/ha N	P	K	Recovery efficiency, % N	P	K	Net benefit, Rs./ha
Control	4.9	83	15	148	-	-	-	11,252
ASI* - P	8.7	191	20.7	248	37	-	67	21,257
ASI + 25% P	9.7	207	28.2	293	43	70	97	27,142
ASI + 50% P	11.7	212	33.8	307	45	50	106	45,272
ASI + 75% P	12.9	224	36.7	346	48	39	132	54,957
ASI + 100% P	13.9	236	40	359	53	38	141	62,497
150% NPK	9.0	224	37	355	32	22	92	19,552
C.D. (p = 0.05)	0.47	3.5	1.8	20	-	-	-	

Source: Pattanayak et al., 2008
*ASI = Agro Services International analytical method (Portch and Hunter, 2002).
*Costs considered for calculation of economics are from 2008: hybrid rice = 8.5 Rs./kg, N = 11 Rs./kg, P_2O_5 = 22 Rs./kg, K_2O = 8 Rs./kg, borax = 90 Rs./kg, zinc sulphate = 55 Rs./kg, and copper sulphate = 160 Rs./kg.

revealed that application of P sources significantly increased the grain yield of rice, the highest grain yield recorded with the application of a complex fertilizer source (20:20:0:13) followed by combined application of Mussouriee RP (MRP) + single superphosphate (SSP) (1:1 proportion). Relative agronomic efficiency (RAE) with insoluble low cost P source (MRP) was lower than the complex sources and SSP + MRP mixture (1:1), which had a significantly higher RAE compared to the sole source MRP (**Table 1**). The authors attributed better efficiency of SSP + MRP mixture to the combined effect, where SSP helped in meeting the immediate crop P requirement and the rest of the P requirement was met from the slow dissolution of MRP under acidic soil condition. Mitra et al. (1993) reported similar results in rice-groundnut cropping system in the alluvial soils of Puri district with strongly acidic pH (pH 5.3 to 5.5), where 1:1 mixture of SSP + Rajphos performed equivalent to SSP alone in terms of productivity of rice-groundnut cropping system in addition to minimizing P fixation while increasing the availability of P in acid soils.

From this study, combined application of SSP + MRP at 1:1 proportion may be considered as the right source of P in the acid soils due to the cumulative benefits of MRP in alleviating soil acidity and better comparable yield and relative agronomic efficiency of SSP + MRP over complex fertilizer source.

Right Rate of P Application

A study was conducted to evaluate the right P application rate to rice in an acidic soil (Inceptisol, pH 5.0) with sandy texture at the central farm of Orissa University of Agriculture and Technology for two consecutive seasons, namely the winter and summer rice seasons of 2005-06 (Pattanayak et al., 2008). The study consisted of seven treatments including a control, soil test-based recommended dose of fertilizer for rice (i.e., 290 kg N, 170 kg P_2O_5, 180 kg K_2O, 1 kg B, 7 kg Zn, and 14 kg Cu/ha, for two seasons), four treatments with P application rates from 25 to 100% of the soil test-based recommendation in increments of 25%, and a dose having 1.5 times the soil test-based recommended rates for N, P_2O_5 and K_2O (**Table 2**). All the treatments except control received a blanket dose of 5 t FYM/ha and 1,800 kg $CaCO_3$/ha.

Across the treatments, the cumulative yield of rice over two seasons varied from 4.9 to 13.9 t/ha, with highest grain yield of 13.9 t/ha recorded with soil test-based + 100% P (**Table 2**). Omission of P entirely from the fertilizer schedule resulted in 38% yield loss. The study also indicated that P application rate based on soil test resulted in higher nutrient uptake (N, P and K), which tended to plateau or decrease slightly with 1.5 times the soil test-based treatment. Increasing P application in 25% increments increased N and K recoveries considerably to a maximum of 53% for N and 141% for K at the soil test-based P recommendation. Highest net benefit (Rs. 62,497) per ha was also obtained in the soil test-based treatment (**Table 2**).

Based on the results of the study, it was inferred that right P application rates suggested for rice through the soil-test approach was responsible for a 5.2 t/ha grain yield response which raised the potential of a two crop rice system to 13.9 t/ha. In addition to improving rice yields, right rates of P application also increased the recovery efficiency of N and K while creating better economic benefits from hybrid rice cultivation.

Right Time of P Application

While growing crops in acid soils, timing of P application plays a critical role in improving the crop yield and recovery efficiency of applied P. Mitra et al. (1993) conducted a study on timing of P application in rice-groundnut cropping system grown in an acid soil, with P being applied to rice or groundnut grown during the rabi (winter) season. Results revealed that REY (Rice Equivalent Yield) of rice-groundnut cropping system was higher when P was applied to groundnut during winter season (8.3 t/ha) than the application of P to rice grown during the winter season (7.7 t/ha), showing 8% yield increase due to application of P to groundnut. The higher yield in P application timing to groundnut-rice system over the rice-groundnut system is due to higher P uptake (17.6 kg/ha) and higher recovery of applied P (19%), which are 23 and 55% higher than the rice-groundnut system, respectively (**Table 3**). Singh and Singh (2001) reported that rice can generally meet its P requirement utilizing the residual P from an adequately fertilized preceding crop. In the current study, P applied to rabi (dry) season groundnut solubilized more P and the portion that gets fixed during rabi season groundnut becomes available to the following rice crop due to soil reduction during submergence. Misra and Pattananyak (1997) observed similar results in rice-groundnut cropping system grown in the acid alluvial soils of Puri district and reported that application of the entire dose of P to rabi groundnut resulted in improved recovery of applied P in the succeeding crop of rice due to the submergence effect which reduced ferric phosphate to ferrous phosphate and increased the availability of P to rice.

Right Placement of P

Right placement of P fertilizer depends on the P fixation capacity of the soil, P source used, soil P fertility level and tillage practices. In acid soils with high rates of P fixation and prevalence of low soil P fertility levels, banding of P fertilizer is more efficient compared to the broadcast method. Boman et al. (1992) studied the impact of banding P fertilizer with seed on the production of winter wheat forage and reported a two to four-fold increase in the forage yield. Band placement of P has a more immediate impact on alleviating soil acidity than liming, especially under arid conditions, where activation of lime can take a significant amount of time, upwards of one year. Kaitibie et al. (2002) reported superior yield of winter wheat forage with band placement of P over incorporation of lime. For the farmers of Odisha growing second crop in the winter season, the time between the harvest of kharif crop and planting of rabi crop can be quite short and application of lime or any such ameliorating material may not get enough time for activation for alleviating soil acidity. Under such situations, band placement of P fertilizes may achieve better results in addition to applying liming materials.

Band placement of P fertilizers is efficient compared to the broadcast method. Singh and Singh (2001) reported that banding of water-soluble P fertilizers below or near the seed makes the P-source readily available to the roots, reduces the extent of P fixation and improves the uptake by crops. The authors also reported that closer spaced crops (rice, wheat etc.) are benefited from banding, compared to wider spaced crops like maize. However, Abrol and Meelu (1998) reported that broadcasting and mixing P fertilizers to soil during rice transplanting was more effective compared to its placement, whereas, for wheat, results are overwhelmingly in favor of drilling and placing P fertilizers below the soil surface and into the root zone. Tandon (1987) reported wheat yield increase of 400 to 700 kg/ha when P was placed or drilled compared to its broadcasting. Vig and Singh (1983) reported that band placement of P in wheat increased the P use efficiency, which was 1.5 times greater than when broadcasting. In acid soils with extremely low pH and low available P, broadcasting finely ground RP or partially acidulated RP followed by its incorporation is recommended (Singh and Singh, 2001).

Summary

It is highlighted in the above discussion that P nutrition can be better managed in the acid soils of Odisha by applying the principles of 4R Nutrient Stewardship. Application of the right P fertilizer source, at the right rate, right time, and in the right place helped in improving crop yields, in addition to alleviating the negative effects of soil acidity. However, guidelines on practicing 4R for P management in acid soils is limited especially for right placement and there is a need to initiate studies for documenting the benefits of right placement of P fertilizers for the predominant crops grown in Odisha. BC-SA

Table 3. Evaluation of P application timing on rice-groundnut cropping system grown on acid soil.

	---- **Groundnut-Rice ----			---- **Rice-Groundnut ----		
P source*	*REY, t/ha	P uptake, kg/ha	Applied P recovery, %	*REY, t/ha	P uptake, kg/ha	Applied P recovery, %
Control	6.8	12.6	-	6.7	11.0	-
SSP	9.8	20.9	24.0	8.4	16.2	15.0
MRP	8.6	18.7	17.0	7.8	14.6	10.0
URP	8.2	18.0	16.0	8.0	15.3	12.0
Mean	8.3	17.6	19.0	7.7	14.3	12.3

Source: Mitra et al. 1993.
*SSP = single superphosphate, MRP = Mussouriee rock phosphate, URP = Udaipur rock phosphate.
*Rice Equivalent Yield. **P applied to first crop grown during the rabi (winter) season.

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National Events Organized to Celebrate the International Year of Soils – 2015

2015 International Year of Soils

September 28-29, 2015 - New Delhi - IPNI South Asia Program co-organized a **National Dialogue on Efficient Nutrient Management for Improving Soil Health** in collaboration with the Trust for Advancement of Agricultural Sciences (TAAS), Indian Council of Agricultural Research (ICAR), International Maize and Wheat Improvement Centre (CIMMYT), Cereal Systems Initiative for South Asia (CSISA), and the Fertiliser Association of India (FAI).

"Nutrient management is one of the common denominators in the seemingly contrasting objective of maintaining a healthy soil under intensive agricultural production systems," said Dr. Kaushik Majumdar, Director, IPNI South Asia Program. "Application of nutrient best management practices (BMPS) in diverse ecologies and crops is critical to enhance crop production, improve farm profitability and resource efficiency, and reduce environmental footprints of crop production." The dialogue was organized with multiple stakeholder participation to highlight the role of nutrient management in improving soil health and to develop a road-map for implementing nutrient BMPs nationally to ensure food and nutrient security and maintain our soils healthy for future generations. The two-day program was attended by leading scientists, policy makers, the extension specialists from public and private sectors, the fertilizer industry, and the farmers. The outcome of the event is now being used to develop a policy brief for submission to the National Government as a guideline for improving nutrient management strategies for sustainable soil health.

October 8-10, 2015 - Kolkata - IPNI South Asia Program and Indian Society of Soil Science Kolkata Chapter jointly organized a **National Seminar on Soil Health Management and Food Security: Role of Soil Science Research and Education.**

Distinguished speakers from the National Agriculture Research and Extension System, International Organizations and Fertilizer Industry made presentations on topical issues on Soil Health Management, Management of Soil Organics, Climate Change Mitigation, Soil Degradation and Management, and field studies research outcomes during the first two days. The third day of the seminar was devoted to Farmer-Scientist interactions to address on-farm challenges that impact soil health issues. The event was attended by nearly 200 participants from a broad range of stakeholders such as scientists, extension professionals, industry agronomists, and farmers. An educational video on ***4R Nutrient Stewardship of Rice*** was released during the occasion in an effort to build capacity of the extension system to provide nutrient decision support to large number of rice farmers.

New Video Available: 4R Nutrient Stewardship of Rice

4R Nutrient Stewardship is helping to enhance rice productivity in South Asia with better economic returns and environmental sustainability. The video from Burdwan, West Bengal describes an example of how to implement the concept of 4R Nutrient Stewardship in rice. *(Bengali with English subtitles).*

All IPNI videos are available at our YouTube Channel: PlantNutritionInst

Current Research: IPNI South Asia Region

Additional information about this research can be obtained from IPNI Staff, or on-line at: http://research.ipni.net

Development of Soil Fertility Map as a Decision Support Tool for Fertilizer Recommendations in Citrus
Project Leader: Dr. A.K. Srivastava, National Research Center on Citrus, Nagpur, Maharashtra. E-mail: aksrivas_2007@yahoo.co.in. Project IPNI-2010-IND-503

Site-Specific Nutrient Management for a Rice-Wheat System in Punjab
Project Leader: Dr. H.S. Sidhu, CSISA Hub, Punjab Agricultural University. E-mail: h.sidhu@cgiar.org. Project IPNI-2009-IND-507

Site-Specific Nutrient Management for a Rice-Wheat System in Haryana
Project Leader: Dr. B.R. Kamboj, Central Soil Salinity Research Institute, CSISA Hub, Karnal, Haryana. E-mail: m.jat@cgiar.org. Project IPNI-2009-IND-508

Site-Specific Nutrient Management for the Rice-Maize System in Bihar
Project Leader: Dr. M.L. Jat, CIMMYT, New Delhi. E-mail: m.jat@cgiar.org. Project Cooperator: Dr. V.B. Shahi. Project IPNI-2010-IND-509

Assessment of Agronomic and Economic Benefits of Fertilizer Use in Maize Production Systems under Variable Farm Size, Climate and Soil Fertility Conditions in Eastern India
Project Leader: Dr. K. Majumdar, IPNI, Gurgaon, Haryana. E-mail: kmajumdar@ipni.net. Project Cooperators: Drs. A. Kohli, H. Banerjee, R. Kumar, S.K. Pattanayak, S. Dutta, T. Satyanarayana, and M.L. Jat. Project IPNI-2012-IND-521

Nutrient Optimization and Yield Intensification of Major Cereal Systems of Eastern India
Project Leader: Dr. M. Banerjee, Visva Bharati University, Birbhum, West Bengal. E-mail: mbanerjee16@rediffmail.com. Project Cooperators: Drs. G. Malik and D. Maiti. Project IPNI-2013-IND-522

Assessing the Contribution of Nutrients to Yield of Hybrid Rice and Maize through Omission Plot Techniques in Bihar
Project Leaders: Dr. S. Singh, Rajendra Agricultural University, Pusa, Bihar. E-mail: sp26814@gmail.com. Dr. S.P. Singh, Rajendra Agricultural University, Pusa, Bihar. Project Cooperator: Dr. M.P. Singh. Project IPNI-2013-IND-523

Assessment of Nutrient Contribution towards Yield of Bt Cotton through Omission Plot Techniques in Karnataka
Project Leader: Dr. Y.R. Aladakatti, University of Agricultural Sciences, Dharwad, Karnataka. E-mail: yraladakatti@rediffmail.com. Project Cooperators: Drs. D.P. Biradar, Y.K. Singh, and S.K. Pattanayak. Project IPNI-2013-IND-524

Evaluating Principles of 4R Nutrient Stewardship in the Rice-Maize-Greengram Cropping System for Improved Productivity and Profitability of Farmers in Odisha
Project Leader: Dr. S.K. Pattanayak, Orissa University of Agriculture and Technology, Odisha. E-mail: sushanta_1959@yahoo.com. Project IPNI-2014-IND-525

Indigenous Nutrient Supplying Capacity of Vertisols under Cotton and Soybean
Project Leader: Dr. V.K. Kharche, Panjabrao Deshmukh Krishi Vidyapeeth, Maharashtra. E-mail: vilaskharche@rediffmail.com. Project Cooperators: Drs. R.N. Katkar, N.M. Konde, B.A. Sonune, A.N. Paslawar, and Shri. P.N. Magare. Project IPNI-2013-IND-526

Assessment of Agronomic and Economic Benefits of Fertilizer Use in Maize Production Systems under Variable Farm Size, Climate and Soil Fertility Conditions in Odisha
Project Leader: Dr. S.K. Pattanayak, Orissa University of Agriculture and Technology, Odisha. E-mail: sushanta_1959@yahoo.com. Project Cooperator: Dr. M. Madal. Project IPNI-2013-IND-527

Global Maize Project in India: Dharwad, Karnataka – Site-Specific Nutrient Management in Maize-Wheat cropping system in Northern Karnataka
Project Leader: Dr. Y.R. Aladakatti, University of Agricultural Sciences, Dharwad, Karnataka. E-mail: yraladakatti@rediffmail.com. Project IPNI-2009-IND-GM23

Global Maize Project in India: Ranchi, Jharkhand – Site-Specific Nutrient Management in Maize-Wheat cropping system in Ranchi, Jharkhand
Project Leader: Dr. R.K. Saxena, Birsa Agricultural University, Ranchi, Jharkhand. E-mail: rkssacbau@gmail.com. Project IPNI-2009-IND-GM22

Optimizing Nutrient Use Efficiency Under Zero Tillage Operations in Rice-Maize Cropping System in Coochbehar and Malda District of West Bengal
Project Leader: Dr. A.K. Sinha, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal. E-mail: abskvk@yahoo.co.in. Project IPNI-2015-IND-536

Assessment of Agronomic and Economic Benefits of Fertilizer Use in Maize Production Systems under Variable Farm Size, Climate and Soil Fertility Conditions in Karnataka of Peninsular India.
Project Leader: Dr. M.A. Basavanneppa, University of Agricultural Sciences (Raichur) Siruguppa, Karnataka. E-mail: basavanneppa6@gmail.com. Project IPNI-2015-IND-530

Assessing the Indigenous Nutrient Supplying Capacity of Soils to Soybean in Vertisols of Northern Karnataka
Project Leader: Dr. Y.R. Aladakatti, Agricultural Research Station, Dharwad, Karnataka, India, E-mail: yraladakatti@rediffmail.com. Project IPNI-2015-IND-531

Agronomic, Economic, Social and Environmental Benefits of Improved Nutrient Management Practices in Maize Production Systems under Variable Farm Size, Climate, Soil Fertility Conditions and Farmer Resource Endowment in Telangana, India
Project Leader: Dr. A. Madhavi, Professor Jayashankar Telangana State Agricultural University, Rajendra Nagar, Hyderabad, Telangana. E-mail: madhavi.adusumilli@gmail.com. Project IPNI-2015-IND-532

Yield Maximization in Cotton through Targeted Yield Approach and Omission Plot Techniques in Vertisols of Karnataka
Project Leader: Dr. B.M. Chittapur, University of Agricultural Sciences, Raichur, Karnataka. E-mail: druasr@rediffmail.com. Project IPNI-2015-IND-533

Study of Variable Nutrient Responses in Cotton Grown in Vertisols of Northeastern Karnataka
Project Leader: Mr. A. Naik, University of Agricultural Sciences, Raichur, Karnataka. E-mail: anandnaik2@gmail.com. Project IPNI-2015-IND-534

Indigenous Nutrient Supplying Capacity of Soils under Soybean in Odisha
Project Leader: Dr. S.K. Pattanayak, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha. E-mail: sushanta_1959@yahoo.com. Project IPNI-2015-IND-535

On-Farm Precision Nutrient Prescription under Pre-Dominant Cereal-Cereal Systems using Nutrient Expert®
Project Leader: Dr. V.K. Singh, ICAR-Indian Institute of Farming System Research, Modipuram, Meerut, Uttar Pradesh. Project IPNI-2014-IND-528

Dissemination of Nutrient Expert® Fertilizer Decision Support Tool for Wheat and Maize in Eastern India.
Project Leader: Dr. A.K. Singh, ICAR-Agricultural Technology Application Research Institute, Zone II, Kolkata, West Bengal. E-mail: zpdkolkata@gmail.com. Project IPNI-2014-IND-529.

Transfer, Evaluation and Dissemination of an Innovative Fertilizer Management Tool Nutrient Expert® for Increasing Crop Yields and Farmers' Income in Eastern Nepal
Project Leader: Dr. N.P. Sen, FORWARD Nepal. E-mail: netrapsen@wlink.com.np. Project IPNI-2014-NPL-1

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Farmers showing Nutrient Expert® fertilizer recommendation being applied to their rice.

Achieving success at work…a goal we all seek in our working life. This is the situation that the IPNI staff in South Asia now finds themselves, after a number of years of dedicated efforts to develop, evaluate and validate the Nutrient Expert® decision support tool. The tool is now widely accepted by partners in the national, state and university systems as an effective method of making fertilizer recommendations. However, with success comes additional challenges, in this case the development of effective partnerships to disseminate Nutrient Expert to as wide an audience as possible.

Trusting the science to make better nutrient recommendations. When the program to evaluate and test Nutrient Expert was established in South Asia, one of our key approaches was to engage with as large a group as possible. This meant holding group meetings that involved not only our traditional partners in research, but also more importantly, extension workers from government and industry, as well as farmer organizations in regions we were working within. At all of these meetings we engaged with this diverse group of partners to explain and develop coordinated plans to ensure that we had a solid scientific foundation on which to advance our ideas. We knew that if we moved forward with good science, the opportunity to make sound decisions with the results would find wide acceptance with our partners.

Moving from field verification to last-mile delivery. With a solid foundation of Nutrient Expert for wheat, maize and rice, IPNI staff is now working to engage a wide array of potential users of the decision support tool. This involves holding training events for agronomy advisors who work with farmers in government, universities and industry. It involves the challenge of finding capable individuals who can carry the Nutrient Expert message to their associates in an even wider network of training. And finally, it involves IPNI developing web-based tools for the easy access and use of Nutrient Expert by all interested individuals across South Asia. This web-based version of Nutrient Expert is not only usable on lap-top computers, tablets and smart phones, but is also accompanied by a series of local language videos and user guides, a complete package for users.

The march toward change…the evolution of future food security in South Asia. Equipped with a tool like Nutrient Expert, we expect to see significant changes in the delivery of balanced fertilization recommendations across South Asia. With an expanding population, the need to meet regional food security will become an ever-increasing priority. However, we are well aware that major changes in fertilizer use practices, necessary to address the unbalanced use of nutrients currently holding back crop production in the region, requires more than good recommendations. Lets hope that the successes we have achieved in our agronomic efforts are soon reflected in the policy decisions by regional governments.

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