BETTER CROPS
SOUTH ASIA

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In This Issue...

Release of Better Crops South Asia Coincides with 3rd International Agronomy Congress

Nutrient Expert™ as an Evaluation Tool for Maize and Wheat

Economics of Fertiliser Application in Rice Grown on the Indo-Gangetic Plains

Also:

IPNI Scholar Award Winners

...and much more

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BETTER CROPS–SOUTH ASIA

Volume 6, Number 1, November 2012

Our cover: Rice harvest in Murshidabad district, West Bengal
Photo by Kaushik Majumdar

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CONTENTS

Note to Readers: **Articles which appear in *BETTER CROPS–SOUTH ASIA* can be found as PDF files at the IPNI-South Asia website: www.ipni.net/bcsasia**

Welcome to Better Crops South Asia 2012

On behalf of the International Plant Nutrition Institute (IPNI) it is a pleasure to introduce our 2012 edition of *Better Crops South Asia*. This is the sixth issue–released annually in the fourth quarter–that follows a format similar to our quarterly publication known as *Better Crops with Plant Food*.

For 2012 we are happy to release this publication to coincide with the 3rd International Agronomy Congress on agriculture diversity, climate change management, and livelihoods being held in New Delhi November 26 to 30th. We applaud the organizing committee of the conference for their great efforts and wish them success in the conference. *Better Crops South Asia* features research articles and information pertinent to this specific region. The research featured 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 in a positive mode for South Asian agriculture.

Dr. Terry L. Roberts, President, IPNI

2012 Scholar Award Recipients Announced by IPNI

The 2012 winners of the IPNI Scholar Award have been selected. The awards of USD 2,000 (two thousand dollars) are available to graduate students in sciences relevant to plant nutrition and management of crop nutrients. "Solid interest in the IPNI Scholar Award was once again apparent based on the quantity of applications received from a global mix of agricultural researcher centers, this year located in Argentina, Australia, Brazil, China, India, Russia, South Africa, Sri Lanka, Uruguay, and the United States," said Dr. Terry L. Roberts, IPNI President. "Being selected from this group is a great accomplishment that each student should be proud of, as should their advisers, professors, and supporting institutions. Our selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic achievements."

In total, 24 graduate students were named to receive the IPNI Scholar Award in 2012. The three winners from the South Asia Region are:

Mr. Pardeep Kumar, Punjab Agricultural University in Ludhiana, India.
Ms. Ekta Joshi, Indian Agricultural Research Institute in New Delhi, India.
Ms. Angelene Mariaselvam, University of Peradeniya in Peradeniya, Sri Lanka.

Funding for the Scholar Award program is provided through support of IPNI member companies, primary producers of N, P, K, and other fertilisers. Graduate students attending a degree-granting institution located in any country with an IPNI program region are eligible. Following is a brief summary for each of the winners from South Asia.


Pardeep Kumar

Mr. Pardeep Kumar is pursuing his Ph.D. in Agronomy at Punjab Agricultural University in Ludhiana, India. The focus of his present research is on agronomic biofortification and enhancement of productivity of bread wheat varieties, where he is studying the impact of nutrient management on growth, productivity, and quality of common bread wheat varieties popular in the region, and also the agronomic biofortification of wheat grains by managing N, Zn Fe, Mn, and Cu at critical phenological stages of wheat through soil and/or foliar fertilization strategies. He has an excellent record of academics, co-curricular activities, and extension services. In the future, Mr. Kumar wants to continue his research efforts in crop nutrition and do a postdoctoral fellowship in the United States.


Ekta Joshi

Ms. Ekta Joshi is working toward a Ph.D. in Agronomy at Indian Agricultural Research Institute in New Delhi, India. Her dissertation is titled "Nutrient omission studies in maize-wheat cropping system". The main objectives of her study are to: (a) determine indigenous nutrient supplying capacity of soil, (b) develop soil-test based recommendations for N, P, K, and Zn for different yield targets of wheat and maize, (c) determine the effect of omitted nutrients on soil quality and soil microbial population, (d) work out a site-specific nutrient management strategy for the maize-wheat system, (e) develop an apparent soil nutrient balance sheet, and (f) assess the direct, residual, and cumulative effect of omitted nutrients on productivity and profitability of maize and wheat crops and as maize-wheat system. For the future, Ms. Joshi hopes to become an agricultural scientist working on soil fertility and soil biology.


Angelene Mariaselvam

Ms. Angelene Mariaselvam is completing requirements for her master of philosophy degree at University of Peradeniya in Peradeniya, Sri Lanka. Her thesis title is "Improving a low productive Ultisol soil through fertility enhancement and carbon stocks improvement". This study has two main objectives including the selection of a suitable organic amendment to improve soil carbon stock, and developing a beneficial nutrient management practice specific to the area. The work is expected to pave the way for future research on specific nutrient management practices to improve marginal agricultural lands. BC-SA

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium, Cu = copper; Fe = iron; Mn = manganese.

Nutrient Expert™: A Tool to Optimise Nutrient Use and Improve Productivity of Maize

By T. Satyanarayana, K. Majumdar, M. Pampolino, A.M. Johnston, M.L. Jat, P. Kuchanur, D. Sreelatha, J.C. Sekhar, Y. Kumar, R. Maheswaran, R. Karthikeyan, A. Velayutahm, Ga. Dheebakaran, N. Sakthivel, S. Vallalkannan, C. Bharathi, T. Sherene, S. Suganya, P. Janaki, R. Baskar, T.H. Ranjith, D. Shivamurthy, Y.R. Aladakatti, D. Chiplonkar, R. Gupta, D.P. Biradar, S. Jeyaraman, and S.G. Patil.

Nutrient Expert (NE)-based field-specific fertiliser recommendations offered solutions to the farmers of southern India for better nutrient use in maize under the current scenario of escalating fertiliser prices. Results from validation trials, comparing NE-based recommendations with FP and SR in 82 farmer fields of southern India, demonstrated the utility of the decision support system tool in improving the yield and profitability of maize farmers in the region.

Maize, a crop of worldwide economic importance, together with rice and wheat, provides approximately 30% of the food calories to more than 4.5 billion people in 94 developing countries, and the demand for maize in these countries is expected to double by 2050. In India, maize is considered as the third most important food crop among the cereals and contributes to nearly 9% of the national food basket (Dass et al., 2012). The annual maize production of the country is about 21.7 million t with an annual growth rate of 3 to 4 % (ASG, 2011). Maize yields in India need to be increased significantly to sustain this growth rate and there is a need to further increase the productivity of maize to efficiently meet India's growing food, feed and industrial needs.

In Southern India, farmers are substituting maize for traditional crops such as rice wherever there is a drop in the water table due to over use of water by the rice crop. Maize is considered as a viable option for diversifying agricultural production, owing to its adaptability in multiple seasons under different ecologies. Recently, maize is gaining popularity as a rice-maize cropping system in the state of Andhra Pradesh, replacing the second rice crop in the existing rice-rice or rice-rice-pulse cropping systems due to water scarcity in rice and incidence of diseases in pulses. Similarly, maize is also becoming an important crop in Tamil Nadu and Karnataka due to its higher productivity and profitability, and is grown either as a sole crop in *Kharif* or in sequence after rice during the *Rabi* season. In the emerging rice-maize system in the region, the maize crop following rice is mostly grown under no-till conditions due to lack of time between crops for preparatory cultivation. Farmers in the region lack knowledge about managing nutrients within this highly demanding cereal system and are often applying inadequate and imbalanced rates. This has resulted in uncertain system yields and raised doubts on long-term sustainability. Further, conservation tillage systems pose greater challenges for farmers due to lack of information on efficient nutrient management strategies under these systems.

The average maize yields in southern India are much lower than reported attainable yields and one of the key factors responsible for low yields is inadequate and improper fertilisation. Current fertiliser use is quite imbalanced to achieve maximum economic yields for new maize hybrids used by farmers. Moreover, nutrient requirement varies from field-to-field due to high variability in soil fertility across farmer fields, and single homogenous and sub-optimal official state recommendations may not be very useful in improving maize yields. Also, the current scenario of escalating prices of fertilisers demands solutions for optimised use of nutrients. Thus, there is ample opportunity to improve maize yields through the right use of nutrients. Nutrient Expert, a new, nutrient decision support system (DSS) based on the principles of site-specific nutrient management (SSNM), offers solutions for providing field-specific fertiliser recommendations to improve the yield and economics of maize growing famers in the region.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Zn = zinc; Mn = manganese; Fe = iron; B = boron; CO_2 = carbon dioxide; FP = farmer practice; SR = state recommendation.

IPNI, CIMMYT, and UAS Raichur staff visiting the Nutrient Expert validation trials at CSISA hub site in Bheemarayanagudi, Karnataka.

While generating recommendations, NE considers yield response and targeted agronomic efficiency in addition to quantifying the contribution of nutrients from indigenous sources. It also considers other important factors affecting nutrient management recommendations in a particular location and enables crop advisors to provide farmers with fertiliser guidelines that are suited to their farming conditions. The tool uses a systematic approach of capturing site information that is important for developing a location-specific recommendation (Pampolino et al. 2012a). Currently, IPNI has developed NE for different geographies of Asia and Africa. The objective of this paper is to evaluate and compare the performance of NE-based fertiliser recommendation with FP and SR, and demonstrate the merits of using NE in maize by presenting results from on-farm evaluation trials conducted in southern India.

Field evaluation of NE maize was conducted in varying maize growing environments, under rainfed and assured irrigated conditions, at 82 major maize growing sites in southern India. The study area covered Karimnagar, Ranga Reddy, Guntur, and West Godavari districts of Andhra Pradesh; Dharwad, Gulbarga, Yadgir, and Bangalore districts of Karnataka; and Perambalur, Dindigul, Thanjavur, and Coimbatore districts of Tamil Nadu during the *Kharif* and *Rabi* seasons of 2011-12. The experiments were carried out by the International Plant Nutrition Institute (IPNI) in collaboration with the Interna-

Table 1. Comparison of nutrient use across three nutrient management options.

		Kharif 2011 (Monsoon season)					Rabi 2011-12 (Winter season)				
Parameter	Unit	FP[1]	SR	NE	NE-FP		FP	SR	NE	NE-FP	
		Andhra Pradesh (n = 8)					Andhra Pradesh (n = 27)				
Fertilizer N	kg/ha	121-550 (229)	180	110-210 (148)	-82	ns	140-855 (288)	200	150-230 (203)	-85	**
Fertilizer P_2O_5	kg/ha	38-230 (87)	60	17-64 (37)	-51	ns	25-753 (153)	60	27-71 (54)	-99	***
Fertilizer K_2O	kg/ha	42-150 (74)	50	18-55 (38)	-35	ns	0-168 (68)	50	51-104 (74)	6	ns
		Karnataka (n = 12)					Karnataka (n = 11)				
Fertilizer N	kg/ha	80-174 (125)	150	110-230 (152)	27	*	80-218 (130)	150	110-190 (154)	24	ns
Fertilizer P_2O_5	kg/ha	58-148 (113)	75	20-81 (38)	-75	***	58-115 (77)	75	17-64 (42)	-35	***
Fertilizer K_2O	kg/ha	23-110 (67)	75	22-104 (62)	-5	ns	0-75 (29)	75	29-81 (57)	28	*
		Tamil Nadu (n = 12)					Tamil Nadu (n = 12)				
Fertilizer N	kg/ha	147-332 (225)	135	130-210 (182)	-43	*	95-360 (210)	210	130-150 (148)	-62	*
Fertilizer P_2O_5	kg/ha	48-79 (67)	63	27-47 (42)	-25	***	25-258 (111)	70	28-47 (39)	-72	*
Fertilizer K_2O	kg/ha	48-352 (201)	50	29-55 (43)	-158	***	50-270 (128)	65	22-59 (31)	-97	**
		Southern India (n = 32)					Southern India (n = 50)				
Fertilizer N	kg/ha	80-550 (193)	-	110-230 (161)	-32	ns	80-855 (209)	210	110-230 (168)	-41	**
Fertilizer P_2O_5	kg/ha	38-230 (89)	-	17-81 (39)	-50	***	25-753 (114)	70	17-71 (45)	-69	***
Fertilizer K_2O	kg/ha	23-352 (114)	-	18-104 (48)	-66	***	0-270 (75)	65	22-104 (54)	-21	ns

***, **, *significant at $p < 0.001$, 0.01, and 0.05 level; ns = non-significant.
[1]FP, SR, and NE = Farmer Practice, State Recommendation, and Nutrient Expert.
Values in parenthesis represent mean values

tional Maize and Wheat Improvement Centre (CIMMYT), the Directorate of Maize Research (DMR), state agricultural universities (UAS Dharwad, UAS Raichur, and TNAU Coimbatore), Industry (Canpotex, Coromandel International Ltd., and Bayer BioScience Ltd.), and farmers. A survey was carried out in all locations prior to initiation of experiments and the current maize yields along with the nutrient application rates were recorded to understand the actual yields realised by the farmers. Nutrient Expert was used to provide field-specific fertiliser recommendations for an attainable yield target at each site, which was tested against fertiliser recommendations followed in SR and FP. Conventional (CT) and conservation tillage (CA) were considered as the options of crop establishment. There were 26 sites under CT and 6 sites under CA during the *Kharif* season, whereas, 31 sites had no-till (CA) and the remaining 29 sites were grown under CT during the *Rabi* season. Performance of NE was evaluated in terms of fertiliser use, maize grain yield, fertiliser cost, and gross returns above fertiliser cost (GRF).

Comparison of Fertiliser Use (FP vs. SR vs. NE)

A survey conducted on fertiliser use revealed that the nutrient use by maize growing farmers is highly skewed in southern India (**Table 1**). In *Kharif*, nutrient use data in three southern states indicated that N, P_2O_5, and K_2O fertiliser use in FP varied from 80 to 550, 38 to 230, and 23 to 352 kg/ha, with an average of 193, 89, and 114 kg/ha, respectively. The corresponding NPK use based on NE recommendations varied from 110 to 230, 17 to 81, and 18 to 104 kg/ha, with an average of 161, 39, and 48 kg/ha, respectively. The NE-based fertiliser recommendations reduced N, P_2O_5, and K_2O use by 32, 50, 66 kg/ha indicating 17, 56, and 58% reductions in fertiliser use over FP. Close observation of data in **Table 1** for nutrient use in *Kharif* further revealed that the lowest N use in FP has increased from 80 to 110 kg/ha in NE, whereas, the maximum N use in FP has decreased from 550 to 230 kg/ha in the NE-based recommendations. This indicates that NE, in addition to suggesting a right rate of nutrients sufficient to meet the attainable yield targets, also helps in optimising nutrient use through appropriate reductions in fertiliser application. Similar observations were also noted for optimising P_2O_5 and K_2O use with NE-based fertiliser recommendations (**Table 1**). The difference between NE and FP for N and P_2O_5 use in Karnataka and NPK use in Tamil Nadu were statistically significant.

NE-based fertiliser application during *Rabi* season re-

Table 2. Performance of NE-based recommendations for yield and economics of maize in southern India.

Parameter	Unit	Kharif 2011 (Monsoon season) FP[2]	SR	NE	NE-FP		Rabi 2011-12 (Winter season) FP	SR	NE	NE-FP	
		Andhra Pradesh (n = 8)					Andhra Pradesh (n = 27)				
Grain Yield	kg/ha	7,254	7,569	8,007	753	*	8,568	8,635	9,699	1,131	***
Fertilizer Cost	Rs/ha	6,820	4,991	3,580	-3,240	ns	9,509	5,220	5,459	-4,050	**
GRF[1]	Rs/ha	65,586	72,114	75,211	9,625	*	76,167	80,894	91,770	15,603	***
		Karnataka (n = 12)					Karnataka (n = 11)				
Grain Yield	kg/ha	5,214	5,907	7,026	1,812	***	8,831	9,385	10,215	1,384	**
Fertilizer Cost	Rs/ha	6,335	5,543	4,112	-2,223	**	4,522	5,543	4,183	-339	ns
GRF	Rs/ha	45,809	54,958	64,716	18,907	***	83,784	89,671	96,602	12,818	***
		Tamil Nadu (n = 12)					Tamil Nadu (n = 12)				
Grain Yield	kg/ha	8,154	7,622	8,774	620	**	6,550	7,114	7,405	855	***
Fertilizer Cost	Rs/ha	8,488	4,514	4,232	-4,256	***	8,395	5,960	3,546	-4,849	**
GRF	Rs/ha	73,058	71,988	83,230	10,172	***	57,106	67,595	68,099	10,993	***
		Southern India (n = 32)					Southern India (n = 50)				
Grain Yield	kg/ha	6,874	7,033	7,936	1,062	***	7,983	8,378	9,106	1,123	***
Fertilizer Cost	Rs/ha	7,214	5,016	3,975	-3,239	***	7,475	5,574	4,396	-3,079	***
GRF	Rs/ha	61,484	66,353	74,386	12,902	***	72,352	79,387	85,490	13,138	***

***, **, *significant at $p < 0.001$, 0.01, and 0.05 level; ns = non-significant.
[1]GRF = gross return above fertilizer cost.
[2]FP, SR, and NE = Farmer Practice, State Recommendation, and Nutrient Expert.
Prices (in Rs/kg): Maize = 10.00; N = 11.40; P_2O_5 = 32.2; K_2O = 18.8

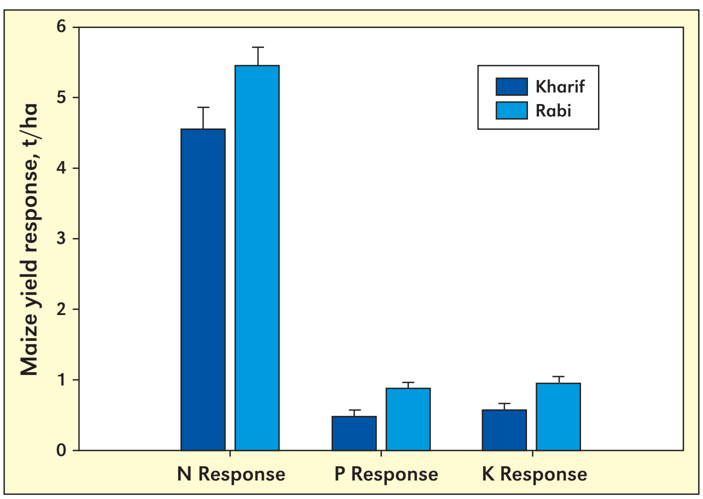

Figure 1. Average maize yield response to NPK application across growing seasons in Southern India (all 82 sites).

vealed that application of N, P_2O_5, and K_2O across the states of southern India varied from 110 to 230, 17 to 71, and 22 to 104 kg/ha with an average of 168, 45, and 54 kg/ha, respectively (**Table 1**). Across all sites, NE-Maize reduced N, P_2O_5, and K_2O rates by 41, 69, and 21 kg/ha over FP, resulting in a rate reduction of 20, 61, and 28% of N, P, and K fertilisers, respectively. NE-maize recommended slightly higher N, P_2O_5, and K_2O rates during *Rabi* in comparison to the *Kharif* season. This is due to the fact that nutrient rates generated through NE are based on the estimated yield response to NPK application and NE estimated relatively high yield responses in *Rabi* season over the *Kharif* season (**Figure 1**). The mean yield response to application of N, P_2O_5, and K_2O during *Kharif* were 4.56, 0.48, and 0.58 t/ha; whereas, the estimated responses during *Rabi* were 5.47, 0.9, and 0.95 t/ha, respectively.

Performance of NE-Maize in Conventional vs. Conservation Tillage Areas

Conservation tillage practices are gaining importance in southern India. The study area had 6 out of 32 locations in *Kharif* and 31 out of 52 locations in *Rabi* season with CA where maize did not receive preparatory cultivation and was grown under no-till conditions. Nutrient recommendations from NE-Maize were tested against FP and SR under CT and CA during both the growing seasons. Across seasons, NE recorded higher grain yield in CA (9.3 t/ha) in comparison to CT (8.4 t/ha) and the magnitude of yield increase over CT (**Figure 2**) was higher in *Kharif* (20%) than in the *Rabi* (3%) season, respectively. Several researchers (Moschler and Martens, 1975; Wells, 1984) comparing CT and no-till production systems suggested that more efficient utilisation of fertiliser with no-till production gave higher yields in CA. Pampolino et al. (2012b) also reported similar observations while evaluating NE-Wheat in different tillage options under varied growing environments.

NE-based Fertiliser Recommendations Improving Yield and Economics of Maize

Data pertaining to relative performance of NE over SR and FP for grain yield of maize, fertiliser cost, and GRF are given in **Table 2**. Across all sites (n=32) during the *Kharif* season, NE-Maize increased yield and economic benefit (i.e. gross return above fertilizer costs or GRF) over FP and SR (**Table 2**). Compared to FP, on average it increased yield by 1.06 t/ha and GRF by 12,902 INR/ha with a significant reduction in fertilizer cost of 3,239 INR/ha. Recommendations from NE-Maize also increased yield (by 0.9 t/ha) and GRF (by 8,033 INR/ha) over SR with a moderate reduction in fertilizer cost

(-1,041 INR/ha). NE-based fertiliser recommendations were also tested against FP and SR during *Rabi* season of 2011-12. Across the three southern states during *Rabi* season (n=50), grain yield with NE was significantly increased by 14 and 9% over FP and SR, respectively (**Table 2**). NE-maize also increased GRF by 13,138 and 6,103 INR/ha over FP and SR and it reduced the fertiliser cost by 3,079 and 1,178 INR/ha over FP and SR, respectively.

Yield improvement with NE-based fertiliser recommendation could primarily be attributed to a balanced application of nutrients than increasing the nutrient rates. The NE program recommended application of secondary and micronutrients especially S, Zn, Mn, Fe, and B at 48 out of 82 locations in the study area (data not shown). Also, farmers in 11 out of 82 locations did not apply K fertilisers under FP, whereas, NE-based recommendations bridged such gaps and provided optimum rates of K recommendations in the respective fertiliser schedules. This clearly explains how NE helped in promoting balanced use of all the essential nutrients thereby improving yields and optimising nutrient use in the maize growing areas of Southern India.

The higher GRF when using NE than in FP and SR justifies the substantial reduction in fertiliser cost with NE-based recommendations. NE-Maize provides nutrient recommendations that are tailored to location-specific conditions. In contrast to SR, which gives one recommendation per state (e.g. 150 kg N, 75 kg P_2O_5, and 75 kg K_2O per ha in Andhra Pradesh), NE recommends a range of N, P_2O_5, and K_2O application rates within a site depending on attainable yield and expected responses to fertiliser at individual farmers' fields. Further, the estimated maize yield response by NE to application of N, P_2O_5 and K_2O fertilisers across the growing seasons varied from 2 to 8, 0 to 1.8, and 0 to 2 t/ha with a mean response of 5.02, 0.69, and 0.77 t/ha (data not shown), and captured the temporal variability of nutrient requirement between seasons along with the spatial variability between farmers'. The varied yield response to N, P, and K application suggests that single homogenous state recommendations (**Table 1**) may become inadequate for improving maize yields in the region. Thus, fertiliser N, P_2O_5, and K_2O requirements determined by NE, varied among fields or locations, proved to be critical in improving the yield and economics of maize farmers in the region. In effect, use of the NE actually increased yields and profit, while reducing economic risk to the farmer, simply by providing some direction in the most appropriate fertilizer rate.

Summary

Maize, owing to its efficient utilisation of radiant energy and fixation of CO_2 from the atmosphere, is considered as one of the major high yielding crops of the world. This versatile crop has wider adaptability to varied growing seasons and diverse ecologies and can address some of the food security issues of the nation. Despite maize being grown predominantly as a rainfed crop, its productivity is more than other cereals like rice and wheat, which are grown under assured irrigated/favorable rainfed conditions in south India. However, maize is an exhaustive feeder of nutrients and balanced and adequate application of fertiliser nutrients is the key not only for improving the current yield levels but also for sustaining the profitability of maize growing farmers in the country. Nutrient Expert-based field

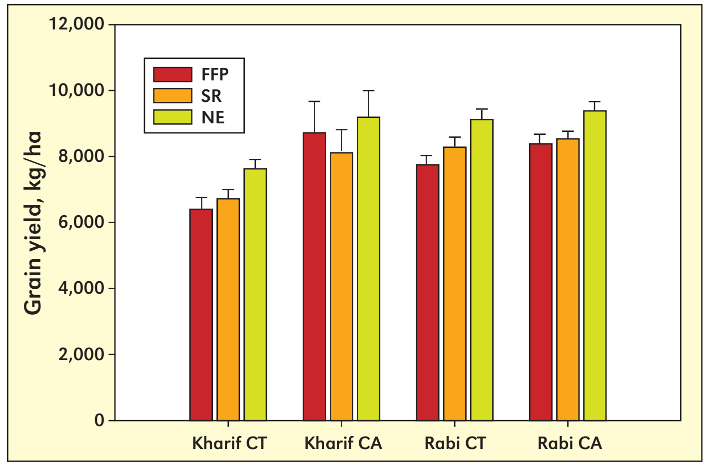

Figure 2. Effect of nutrient management options under varied seasons and crop establishments on grain yield of maize.

specific fertiliser recommendations, demonstrated in southern India, increased yield and economic benefits through balanced application of nutrients. This DSS was able to capture the inherent differences between conventional and conservation practices of crop management, and NE-based fertiliser recommendations generated on the principles of SSNM performed better than FP and SR for maize. Besides providing location-specific nutrient recommendations rapidly, the tool has options to tailor recommendations based on resource availability to the farmers. There is a need to rapidly disseminate NE-based fertiliser recommendations for maize through extension agents and we anticipate that a user friendly tool like NE-Maize, with it's robust estimation of site-specific nutrient recommendations, will be attractive to extension specialists working with millions of small holder farmers in the intensively cultivated maize areas in southern India. BC-SA

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Effect of Spatial and Temporal Variability in Cropping Seasons and Tillage Practices on Maize Yield Responses in Eastern India

By Kaushik Majumdar, M.L. Jat and V.B. Shahi

On-farm trials with spring and winter maize in eastern India showed that maize yields under zero-till (ZT) were higher than those under conventional till (CT) for both seasons, but the opposite was true for variability observed in N, P, and K responses of maize. Omission of N, P, and K from the ample NPK treatment reduced maize yields by varying levels across different sites.

Maize is rapidly emerging as a favourable option for farmers in South Asia as a non-traditional component crop of rice and wheat-based systems. Drivers of this change are higher productivity and profitability, lesser water requirement, and better resilience of maize to biotic and abiotic stresses than rice or wheat. However, high-yielding maize also extracts higher amounts of mineral nutrients from the soil than is extracted by rice or wheat. Therefore, balanced nutrient management in maize should aim to (a) supply fertiliser nutrients according to the demand of the crop and (b) apply nutrients in ways that minimise their loss and maximise their efficiency of use. Also, since maize is grown in eastern India under different cropping seasons, cropping systems, and tillage practices, there is lack of information on how such contrasting practices influence the nutrient supplying capacity of soils. This information is important to optimise nutrient management practices for the maize crop.

Nutrient omission trials (18) were set-up in farmers' fields by IPNI and CIMMYT (International Maize and Wheat Improvement Centre) during spring 2010 and winter 2010-11 (9 trials in each season) under the Cereal Systems Initiative for South Asia (CSISA) project in eastern India. The states of Bihar and West Bengal in eastern India offer variable soil and growing environments, where high-yielding maize is grown in rice-mustard-spring maize and rice-winter maize sequences. On-farm trials were conducted in the districts of Vaishali, Samastipur, Purnea, Kathihar, Begusarai, Patna, and Jamui in Bihar and Uttar Dinajpur and Nadia in West Bengal. These districts fall under the agro-climatic zones of northwest, northeast, and south Bihar alluvial plains and the old and new alluvial zones of West Bengal. The annual precipitation ranges between 1,100 and 1,400 mm in Bihar and between 1,300 and 1,500 mm in West Bengal, while soil textures varied from sandy loam to silty clay loam. The maize crop was planted under CT and ZT practices. Conventional tillage practice involved four preparatory tillage operations with a tractor, while ZT practice involved glyphosate spraying and planting maize two days after the spray without any ploughing. All trials included four treatments including: ample NPK, omission of N with full P and K, omission of P with full N and K, and omission of K with full N and P. Ample NPK rates were 150 to 180 kg N, 70 to 115 kg P_2O_5, and 120 to 160 kg K_2O per ha for maize yield targets between 6 to 8 t/ha. Nutrients were applied in all treatments in excess of the actual requirement of the maize crop to ensure no limitation of nutrients except the omitted one. Deficient secondary and micronutrients, determined using soil tests, were applied at the state recommended application rates. The plant density was kept at 83,333 plants/ha (60 x 20 cm spacing). At maturity, grain yields and total biomass (grain + straw) were determined and adjusted to 13% moisture content. The N, P, and K responses in each farmer's field were estimated using the following equation:

N, P, or K response (kg/ha) = Grain yield in ample NPK plot – Grain yield in N, P, or K omission plot

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; CV = coefficient of variation; IPNI = International Plant Nutrition Institute.

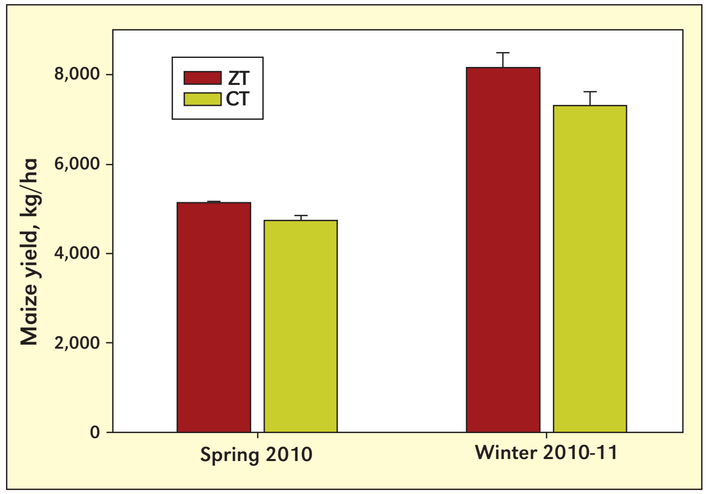

Figure 1. Effect of season and tillage practice (ZT = zero-till; CT = conventional till) on average maize yields in the ample NPK plot in eastern India. The bars represent the standard error.

Results

The average spring maize yield in the ample NPK plot was 4,936 kg/ha with a range of 4,020 to 5,300 kg/ha across all sites and tillage practices (**Figure 1**). In contrast, the range of winter maize yields in the ample NPK plots across sites and tillage practices was 5,630 to 9,420 kg/ha, with a mean yield of 7,749 kg/ha. Favourable climate with a longer grain-filling period (Timsina et al., 2010) and better utilisation of water and fertiliser (Triplett and Van Doren, 1969; Moschler et al., 1972; Moschler and Martens, 1975; Wells, 1984) during the winter season usually results in higher maize yields in the region than spring or rainy seasons. Trials conducted under the All-India Coordinated Maize Improvement Project also revealed that the yield potential of winter maize was about two times that of the summer (monsoon) maize (Dayanand and Jain, 1994).

Omission of nutrients from the ample NPK treatment caused variable yield loss in both spring and winter maize. Data from the omission plot studies in winter maize under ZT showed that omission of N, P, and K from the ample NPK treatment caused an average yield loss of 38, 15, and 12%, respectively (**Figure 2**). Similarly, maize yields and responses to applied nutrients varied considerably across farmer fields, mainly because of small and marginal landholdings that result in high variability in soil characteristics over small distances (Sen et al., 2008). This result was more pronounced in the winter season than in the spring season (**Table 1**). The high CV of N, P, and K responses highlight the high variability in soil nutrient supplying capacity across sites.

Spring maize yield responses were higher in ZT than in CT plots, but no such differences were apparent in winter maize (**Table 1**). This suggests that nutrient omission might cause higher yield loss in ZT spring maize, although higher maize yield levels were attained with ZT than with CT (**Figure 1**). In general, tillage causes short-term and immediate release of indigenous nutrients from inorganic and organic fractions of the soil. Comparatively higher release of indigenous nutrients in tilled N, P, and K omission plots may have attributed to lesser yield loss in the CT plot than in the ZT plot.

Table 1. Descriptive statistics of maize yield response (kg/ha) under zero-till (ZT) and conventional till (CT) in spring 2010 and winter 2010-11.

Treatment	Minimum	Maximum	Mean	Standard deviation	Standard error, ±	CV, %
Spring Maize						
N response ZT	1,450	2,120	1,839	224	75	12
P response ZT	400	840	631	137	46	22
K response ZT	340	860	610	193	64	32
N response CT	400	1,450	959	344	115	36
P response CT	90	1,010	462	251	84	54
K response CT	140	940	492	242	81	49
Winter Maize						
N response ZT	1,900	5,160	3,074	1,174	391	38
P response ZT	940	1,520	1,213	221	74	18
K response ZT	570	1,320	941	263	88	28
N response CT	1,550	4,560	2,744	1,057	352	39
P response CT	630	1,760	1,106	345	115	31
K response CT	340	1,170	752	222	74	30

Higher CVs for nutrient responses in CT plots as compared to ZT plots (**Table 1**) might be due to variation in farmer fields due to the number of tillage operations, depth of tillage, and the extent of residues incorporated during tillage. These factors also compound the inherent variability, due to historical management differences mentioned earlier, in CT fields. For ZT plots, the spatial differences between farm fields are influenced only by historical management differences, thus showing lesser variability than CT fields. However, the very high variability in nutrient responses across fields and establishment practices suggests that such spatial and temporal variability needs to be accounted for while formulating nutrient management strategies in maize. In other words, site-specific nutrient management, based on realistic estimates of indigenous nutrient supply and nutrient requirements for a targeted yield for an individual farmer's field will be required to improve yield and nutrient use efficiencies for higher maize yield and farm profit.

Yield reduction in spring maize N omission plots was found to be higher in ZT plots as compared to CT spring maize (**Figure 3**). Lower yield in N omission plots under ZT probably resulted from either greater immobilisation of available N, losses of N through leaching and denitrification, lower mineralisation of soil organic N, or some combination of these factors (Moschler and Martens, 1975) that reduced the availability of N to maize, particularly in the initial growing phase of the crop. The same trend was not seen in winter maize, where N omission plot yield was higher in ZT than CT plots (**Figure 2**). This is probably related to the difference in duration of spring and winter maize as well as early growth stage temperature. Spring maize was planted in February and had shorter duration (approx. 125 days) than winter maize planted in November (approx. 165 days). Omission of N is expected to cause lesser availability of N to ZT maize in both seasons as compared to CT maize due to the reasons mentioned above. However, due to longer duration of winter maize, any restriction in N availability in the early stages of crop growth in ZT

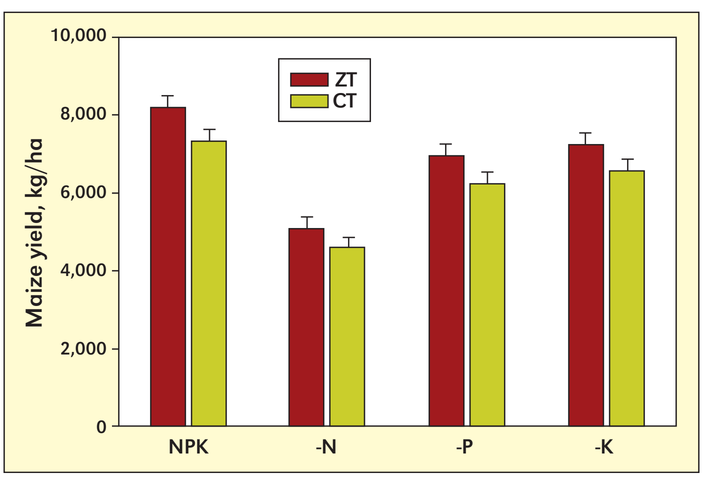

Figure 2. Average yields of winter maize in omission plot trials under zero-till (ZT) and conventional till (CT) systems. The bars represent the standard error.

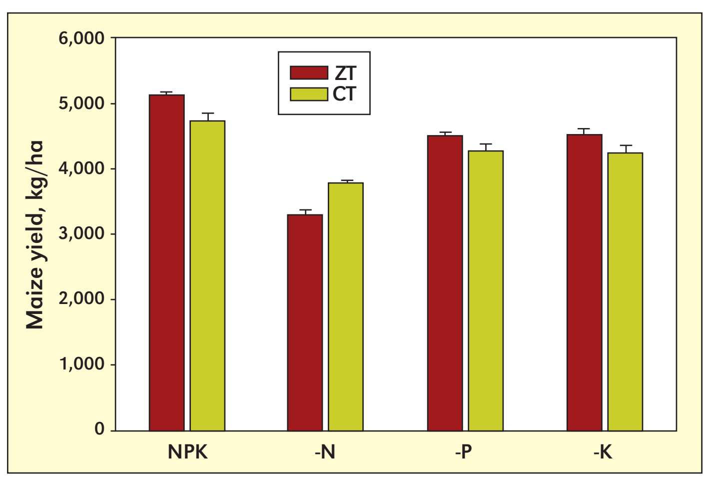

Figure 3. Average yields of spring maize in omission plot trials under zero-till (ZT) and conventional till (CT) systems. The bars represent the standard error.

Effect of contrasting tillage at early growth stage of maize.

plots is expected to cause more yield penalty in the spring crop because of shorter recovery time compared to winter maize. Due to longer duration of winter maize, the mineralisation of the immobilised N might have helped the crop as the physiological stages of N requirement (days after planting for V3 to Vt) occur later than the spring crop. Besides, the average early growth time temperature was higher for spring maize than winter maize. The major phase of N uptake in maize starts at the V3 stage of the crop. Comparatively higher ambient temperature during V3 stage of the crop in spring maize might have caused higher microbial immobilisation of indigenous N and therefore, decreased N availability to the spring crop as compared to the winter crop—leading to more yield penalty.

Maize yields in P or K omission plots were higher in ZT systems as compared to CT plots. In general, tillage was expected to cause greater mineralization, and release of P and K from soil minerals as well as organic phases, leading to higher plant availability of these nutrients in the CT plots. However, release of P and K due to tillage may not be very significant under the prevalent aerobic conditions during maize establishment to override more efficient utilisation of these nutrients under the ZT condition (Timsina et al., 2010). In K omission plots, the contribution of K from crop residues in the ZT system probably helped to increase yield as compared to CT plots. The increased yield in P-omitted ZT plots might be related to higher mineralisation and more efficient utilisation of the indigenous P in presence of higher N and K, but more studies are needed to confirm this effect.

Summary

Results from the farmer field trials in different maize-growing environments of eastern India showed high variability in nutrient supplying capacity of soils. Both spring and winter maize showed higher yield in ZT than the conventionally grown crop. Omission of nutrients in contrasting tillage systems in spring maize suggest greater availability of P and K, but lower availability of N in ZT plots as compared to CT. Lower availability of N in ZT was not apparent in winter maize, which is probably related to growth duration and ambient temperature during the early growth stage of the crop.

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Crop Nutrient Deficiency Photo Contest Entries Due by December 11

December 11, 2012, is the deadline for entries in the annual IPNI contest for photos showing nutrient deficiencies in crops. An individual can submit an entry for each of the four nutrient deficiencies categories: nitrogen (N), phosphorus (P), potassium (K), and other (i.e. secondary nutrients and micronutrients).

Preference is given to original photos with as much supporting/verification data as possible. Cash prizes are offered to First Place (USD 150) and Second Place (USD 75) in each of the four categories, plus a Grand Prize of USD 200 will be awarded to the photo selected as best over all categories. Entries can only be submitted electronically to the contest website: www.ipni.net/photocontest.

Economics of Fertiliser Application in Rice Grown on the Indo-Gangetic Plains

By Sudarshan Dutta, Kaushik Majumdar, M.L. Jat, T. Satyanarayana, Anil Kumar, Vishal Shahi, and Naveen Gupta

In India, the sharp increase in fertiliser prices has raised doubts about the profitability of NPK application in rice, especially when the Minimum Support Price (MSP) and nutrient use efficiencies are low. Spatially distributed on-farm trials indicated variable yield loss of rice due to N, P, or K omissions from the fertilization schedule. On the other hand, economic assessment based on application rates, nutrient response, costs of fertilisers, and minimum support price of rice showed favorable return on investment in all these nutrients.

Rice is one of the major crops grown in the IGP region of India. It is grown on about 42 million (M) ha area with a production of about 89 M t and an average productivity of 2,125 kg/ha (FAI, 2011). However, the last decade (2000 to 2010) has seen no significant increase in productivity of rice. This has made the rice farming community increasingly concerned about the profitability of adequate nutrient application, especially with rising fertiliser prices. Additionally, while N, P, and K are the three primary nutrients for plant growth, farmers tend to apply more fertiliser N due to its lower price and visible impact on crops as compared to other nutrients. This has led to increasing deficiencies of P and K as a result of sub-optimal application or unbalanced use in the intensive cereal-based systems. In several long-term experiments, Subba Rao et al. (2001) observed negative K balances in most soils and cropping systems, even when the so-called optimum rates of NPK were applied. Such an imbalance in N, P, and K applications has negative impact on crop production.

Considering the importance of rice in ensuring the food and nutritional security of India, and also looking at the significant role of NPK inputs for meeting production goals in the coming years, the present study was undertaken to (1) estimate on-farm economic response of NPK application in rice across different soils and farmer management practices in the IGP region and (2) assess the economic profitability of NPK application in rice under current and some hypothetical future fertiliser price and MSP scenarios.

Methods

On-farm trials were conducted across the IGP (Punjab, Haryana and Bihar) during 2009 to 2011 by IPNI in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT) under the Cereal Systems Initiative for South Asia (CSISA) project. Characteristic features of the experimental sites are given in **Table 1**.

The trials included four treatments including (1) ample NPK, (2) omission of N with full P and K, (3) omission of P with full N and K, and (4) omission of K with full N and P. In all treatments, nutrients were applied in excess of the actual requirement of rice following the omission plot experiment protocol to ensure no limitation of nutrients except the omitted

IPNI is collaborating with several agencies to optimise nutrient management in rice.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; IGP = Indo-gangetic plains; MSP = minimum support price; ROI = return on investment; DAP = diammonium phosphate; MOP = muriate of potash or potassium chloride (KCl); Rs = Rupees; Re = rupee.

Table 1. Characteristics of the experimental sites.

State	District	Agro-climatic zone	Soil texture	Average annual precipitation, mm	Cropping system	Ecology	Average farmer-type
Punjab	Ludhiana, Amritsar, Gurdaspur, Sangrur, Fatehgarh Sahib	Central Plain Zone to Sub-Mountain Undulating	Sandy loam to silty loam	600 to 1,020	Rice-Wheat	Favourable rainfed	Resourceful and large farmers
Haryana	Karnal, Kurukashetra, Kaithal, Ambala, Yumnanagar	Northwestern Plain	Sandy loam to clay loam	400 to 600	Rice-Wheat	Favourable rainfed	Resourceful and large farmers
Bihar	Vaishali, Samastipur, Purnea, Katihar, Begusarai, Patna and Jamui	North, West, Northeast and South Bihar Alluvial Plains	Sandy loam to silty clay loam	1,100 to 1,400	Rice-Maize	Favourable rainfed	Poor and small farmers

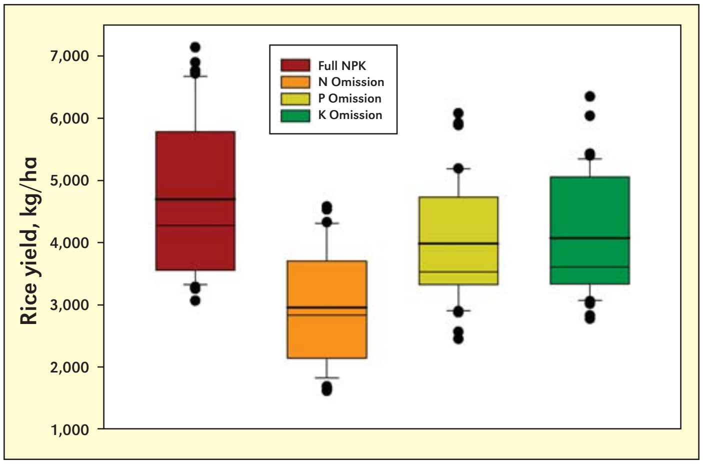

Figure 1. Rice yields in ample NPK and omission plots across 45 experiments locations in the Indo-gangetic plains. The error bars represent 10th to 90th percentile of the data, and the thick line represents the mean.

one. The application rates, based on estimated attainable yield targets between 5 and 8 t/ha, were 125 to 175 kg N/ha, 50 to 80 kg P_2O_5/ha, and 60 to 90 kg K_2O/ha depending on climate, growing environment, and farmer typology. At maturity, grain yields and total biomass (grain + straw yields) were determined and adjusted to 13% moisture content.

The yield response due to nutrient application (such as N response) and nutrient application economics were estimated using the following equations:

Nutrient Response (kg/ha) = Grain yield in ample NPK plot – Grain yield in targeted nutrient omission plot

Return on Investment (ROI) in fertilisers = (Yield increase due to target fertiliser [kg/ha] x MSP of crop [Rs/kg]) / (Applied targeted fertiliser [kg/ha] x cost of the fertiliser [Rs/kg])

The average MSP of rice was Rs. 10/kg during the study period. Return on investment in fertilisers were calculated based on N, P_2O_5, and K_2O prices of Rs. 11.54, 32.2, and 18.8/kg, respectively. Also, the following price levels of fertilisers and MSP range for rice were used to calculate the ROI (Majumdar et al., 2012, Jat et al., 2012; Satyanarayana et al., 2012):

1. Five price levels of N between Rs. 10.5 to 43.48/kg, corresponding to Urea prices between Rs. 4,830 and 20,000/t.
2. Five price levels of P_2O_5 between Rs. 19.26 to 50.20/kg, corresponding to DAP prices between Rs. 10,750 and 25,000/t.
3. Four price levels of K_2O between Rs. 8.43 to 33.33/kg, corresponding to MOP prices between Rs. 5,058 and 20,000/t.
4. Rice MSP levels of Rs. 10 to 15/kg.

The 25th, 50th, and 75th percentiles of the actual N, P, and K responses observed for rice in this study were considered as benchmarks for estimating ROI at current and estimated future prices of fertiliser and MSP of rice.

Results

The average rice yield with ample application of NPK was 4,701 kg/ha with a range of 3,070 to 7,140 kg/ha (**Figure 1**). The average yield across trials was more than double the cur-

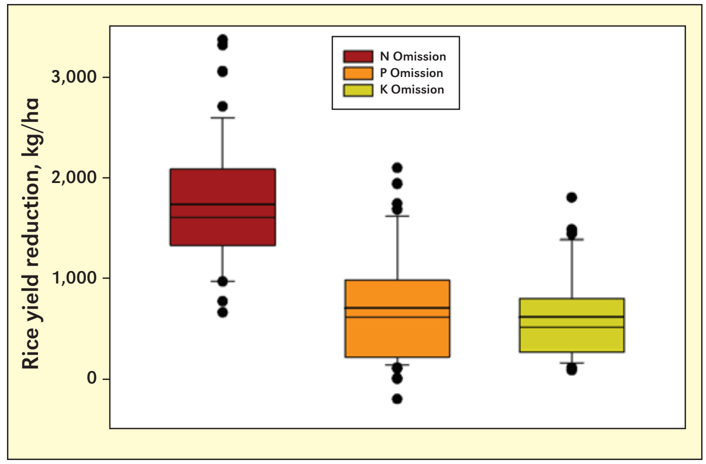

Figure 2. Rice yield loss in N, P, and K omission plots compared against ample NPK plots across 45 experimental locations in the Indo-gangetic plains. The error bars represent 10th to 90th percentile of the data, and the thick line represents the mean.

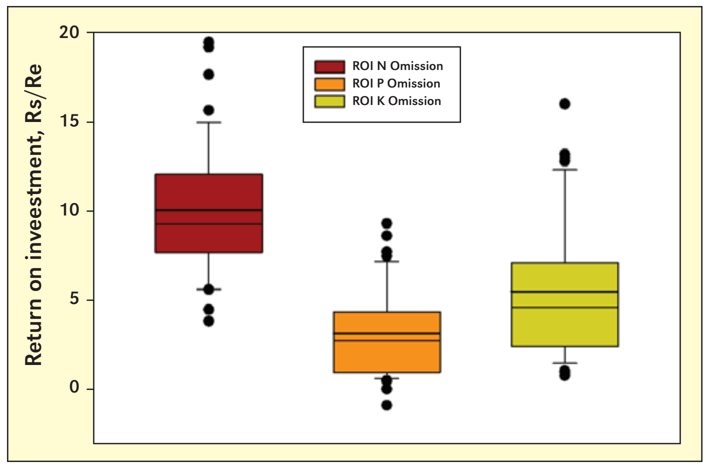

Figure 3. Return on investment in N, P and K fertilisers based on current application rates, fertiliser costs, and minimum support price for rice. The error bars represent 10th to 90th percentile of the data, and the thick line represents the mean.

rent average yield of rice in India. Omission of nutrients from the ample NPK treatment caused variable yield reduction in farmers' plots. Reduction of yield was highest for N omission (667 to 3,370 kg/ha) with an average of 1,739 kg/ha (**Figure 2**). For N omission plots, the results are in agreement with the findings of Saha et al. (2008) who reported a yield response of 1,510 kg/ha with application of N in the long-term fertiliser experiment conducted at Raipur. Yield reductions in P and K omission plots also varied widely across different locations (-194 to 2,100 kg/ha and 90 to 1,806 kg/ha, respectively) with mean respective yield losses of 712 kg/ha and 622 kg/ha. The results clearly highlight the variability of nutrient supplying capacity of rice-growing soils and system management practices by farmers with diverse socio-economic profiles.

Return on investment in fertiliser N ranged from 3.9 to 19.5 (**Figure 3**) with an average of Rs. 10.04 per rupee invested on N. Similarly, ROI in fertiliser P ranged from -0.9 to 4.0 Rs/Re. Average ROI for fertiliser P across locations was 3.0 Rs/Re. ROI was ≤ 1 Rs/Re in 12 locations at an average ample

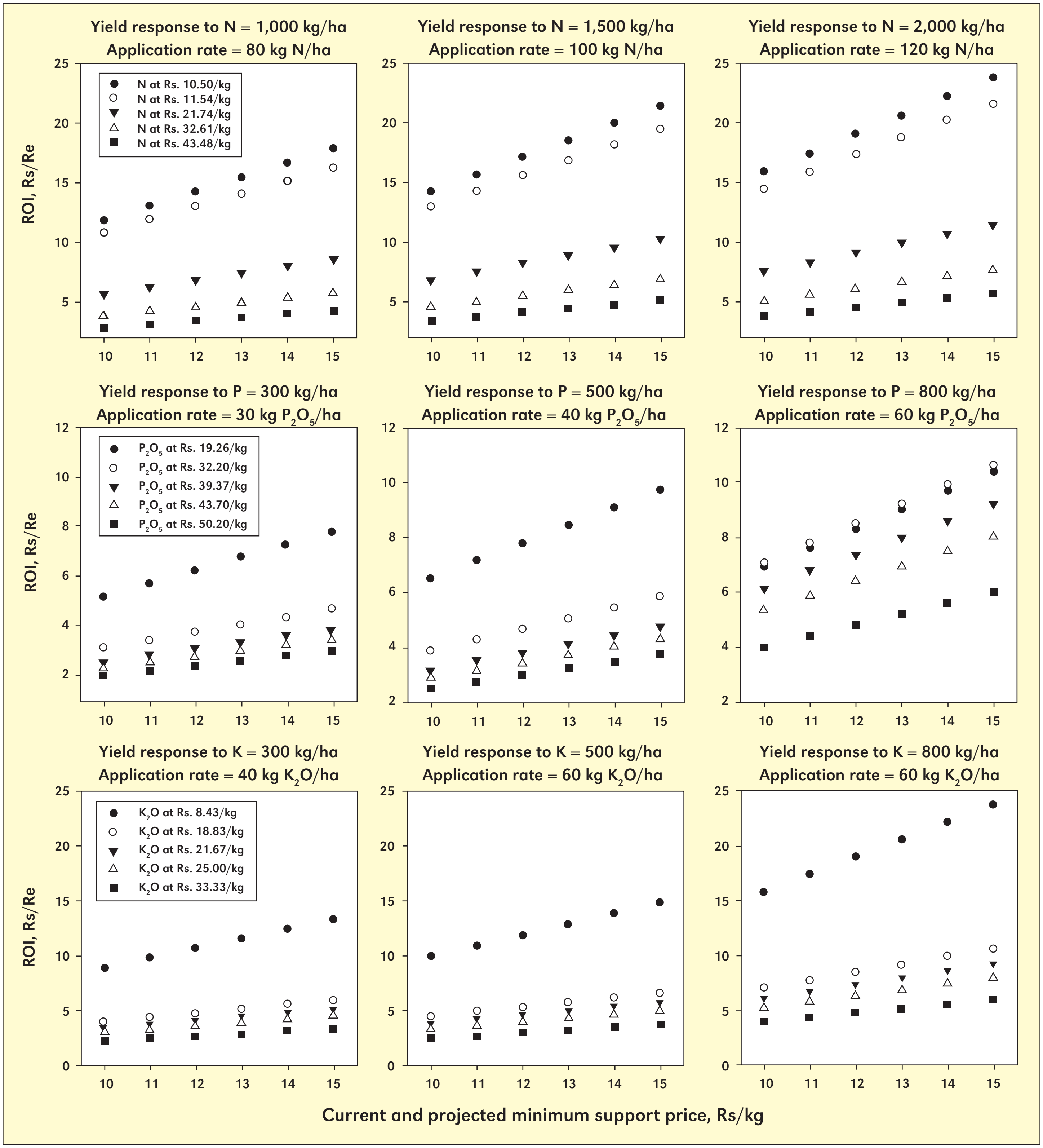

Figure 4. Top Row: Return on investment (ROI) in N fertiliser at different N response levels and projected costs of N fertiliser and minimum support prices for rice. Middle Row: Return on investment (ROI) in P fertiliser at different P response levels and projected costs of P fertiliser and minimum support prices for rice. Bottom Row: Return of investment (ROI) in K fertiliser at different K response levels, projected costs of K fertiliser and minimum support prices for rice.

application rate of 70 kg P_2O_5/ha. Likewise, ROI in fertiliser K ranged between 0.8 to 16 Rs/Re, which revealed that every Rs. invested in fertiliser K produced an additional rice yield worth 0.8 to 16 Rs., with a mean of Rs. 5.5 across the locations. Economic return of < Rs. 1 per rupee invested on K was registered at three locations only.

The results highlight that nutrient responses, and consequently ROI, differed considerably across sites. The economic return from applied fertiliser is integrally related to the crop response to any particular nutrient, which in turn depends on the indigenous nutrient supplying capacity of a particular field or location. Optimising fertiliser application based on expected crop response at a particular field can ensure higher returns from fertiliser application. This is the essence of site-specific nutrient management, where nutrients are applied on the basis of soil nutrient supplying capacity and the nutrient requirement for a particular nutrient. This ensures that nutrients are not under- or over-applied leading to economic loss. The results from rice experiments, showed a wide range of response to N, P, or K application. Breaking up such a range of responses into definite "response segments" and suggesting nutrient application rates that achieve higher yield, higher profit without depleting the soil nutrient resources would ensure food and economic security of the farmers and maintenance of soil health.

Considering the high variability of rice response to N, P, or K fertiliser application across sites, the ROI for the 25th, 50th and 75th percentiles of the actual N, P, and K responses observed in the present experiments were also assessed. We assumed that N response of 1,000 kg/ha justifies application of 80 kg N/ha, while N response of 1,500 and 2,000 kg/ha will require 100 and 120 kg N/ha. Similarly for P, 300 kg/ha of response justifies application of 30 kg P_2O_5/ha, while P response of 500 and 800 kg/ha will require applications at 40 and 60 kg P_2O_5/ha, respectively. A K response of 300 kg/ha justifies application of 40 kg K_2O/ha, while K response of 500 and 800 kg/ha will require applications of 60 kg K_2O ha. The application rate was kept similar for 500 and 800 kg/ha considering generally micaceous mineralogy of the study area soils, high utilization efficiency of K, and cost of fertiliser. The aim of this exercise was to estimate ROI at actual and hypothetical (future scenario) costs of N, P_2O_5, and K_2O as well as at current and projected minimum support prices of rice.

At a rice trial site in Punjab, Dr. Kaushik Majumdar (on left) with participating farmer.

Figure 4 shows that N application, at chosen application rates, is economically profitable. At an application rate of 80 kg N/ha for a 1,000 kg/ha N response, the ROI at the highest price of N (Rs. 43.5/kg) and at the lowest MSP for rice (Rs. 10/kg) was 2.9, suggesting profitable return on N application—even in worst case. Further, the profitability increased with an increase in the MSP of rice as well as the crop response levels. **Figure 4** shows that P application, in general, is economically profitable even in areas where P responses were low (300 kg/ha). At an application rate of 30 kg P_2O_5/ha, the ROI at the highest price of P fertiliser (Rs. 50/kg P_2O_5) and the lowest MSP (Rs. 10/kg rice) was 2 Rs/Re—suggesting profitable return on P application even under low P response situations. Obviously the ROIs increased with increase in the crop response levels. Returns to the farmer could be increased through reasonable increase in MSP of rice under increasing fertiliser price scenarios. **Figure 4** shows that K application at the predetermined rates, in general, is economically profitable even in areas where K response is as low as 300 kg/ha. At an application rate of 40 kg K_2O/ha for a 300 kg/ha response, the ROI at the highest price of K (Rs. 33.33/kg of K_2O) and the lowest MSP (Rs. 10/kg rice) was 2.3—suggesting profitable return on potash application. The profitability increased with increase in the MSP for rice. A yield loss of ≥ 500 kg/ha of rice due to no application of K was observed in more than 50% locations. This suggests that in such locations, application of 40 to 60 kg K_2O/ha will provide a good ROI to the farmers and will also maintain the K fertility status of the soil.

It should be noted that maximum economic yields are obtained only with adequate and optimum nutrient application. The diverse rice-growing environments (soils and climatic conditions) and farmer management practices across the IGP present large variability in nutrient supplying capacity. Therefore, nutrient management decisions in this region must be based on expected nutrient response of rice at a particular location. Providing adequate and balanced rates of N, P, K, and other limiting nutrients, considering the expected yield response in the rice-growing soils of the IGP, will not only help in economic sustainability but also will offer better environmental stewardship of nutrients applied to soil. The general perception that Indian soils are rich in K and, therefore, do not require K application—or that most soils have high build-up of P due to continuous historical application of P fertiliser and may not respond to P application—were not supported by these well distributed, recent on-farm experiments. Rationalisation of fertiliser management strategies, based on spatially and temporally variable crop responses and nutrient balances in highly intensive cereal systems would be required to sustain food and economic security of farmers.

Summary

The study showed a variable reduction in rice yields in N, P, or K omission trials in farmers' fields. The ROI in N, P, and K fertilisers was profitable in most of the cases, even at lowest crop response and with the present MSP for rice. BC-SA

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Precision Nutrient Management Strategies using GIS-based Mapping in Western Uttar Pradesh

By V.K. Singh, V. Govil, S.K. Singh, B.S. Dwivedi, M.C. Meena, V.K. Gupta, K. Majumdar, and B. Gangwar

Site-specific nutrient management (SSNM) 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. Integration of SSNM with GIS-based spatial variability mapping has the potential to become a useful technique for use in large domains.

Nutrient management and recommendation processes in India are still based on response data averaged over a large geographic area. Agricultural holdings in India are highly fragmented; with each farmer managing small field plots separately. This pattern of farming increases variability between fields due to individual farmer knowledge, fertilisation history, crop sequence, farm management, and resource availability. Generalised nutrient recommendation over large areas of such small-scale farming leads to the possibility of over- or under-use of nutrients with adverse economic and environmental challenges. Such farms would require individual attention in terms of nutrient management to attain optimum yield.

The precision nutrient management concept, modified to suit India's unique farming systems, is expected to provide ways to reverse the productivity and fertility trends in India. Geo-statistical analysis and GIS-based mapping can provide an opportunity to assess variability in the distribution of native nutrients and other yield limiting/improving soil parameters across a large area. This can aid in developing appropriate nutrient management strategies leading to better yield and environmental stewardship. Research has shown a direct correlation between variability and production conditions and improvement in production and profit under different scales of operation by managing variability. However, there is a lack of studies integrating GIS with SSNM (Sen et al., 2007, 2008; Iftikar et al., 2010). We conducted a study to characterise existing nutrient management practices and to assess the spatial variability of physico-chemical properties and native nutrient pools in agricultural soils across different cropping systems of western Uttar Pradesh (WUP) using GIS-based mapping.

During 2011-12, a study was conducted in the districts of Muzaffar Nagar, Saharanpur, Baghpat, Ghaziabad, Buland Shahr, Gautam Buddh Nagar, and Meerut in WUP. From these districts, 210 farmers were surveyed and soil samples were collected from their fields. The "Proportionate Area Method" was used for judicious stratification of samples in different districts of WUP. For this, Fertiliser Statistics (FAI, 2011) data on crops and district-wise area were used to identify the predominant cropping systems. The distribution of samples among different cropping systems in a district was determined using Area Spread Index (ASI) approach:

$$ASIC = (ACS/ TACS) \times 100$$

where, ASIC is the Area Spread Index for a cropping system, and ACS and TACS represent net area under a particular cropping system in a district and total area of three predominant cropping systems of that district, respectively.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Ca = calcium; Mg = magnesium; Fe = iron; Cu = copper; Mn = manganese; Zn = zinc; C = carbon; SSP = single super phosphate; DAP = diammonium phosphate; FYM = farmyard manure; GIS = geographic information system; GPS = global positioning system; SAR = sodium adsorption ratio; DTPA = diethylene triamine pentaacetic acid.

Geo-referenced soil samples collected by Dr. V.K. Singh (on left) and his assistant.

In order to select the agricultural development blocks (ADBs) to be targeted for sampling in a particular cropping system, ASIC for a different cropping system was calculated at the block level to determine the spread of a particular cropping system in comparison to the whole district.

For recording current crop/fertiliser management practices, farmers representing different socio-economic groups were selected. Participatory rural appraisal (PRA) methodologies were used to gather survey information on various aspects influencing, directly or indirectly, the nutrient management practices of the farmers. Detailed information on fertiliser and manure use pattern and the productivity levels were also collected. During the survey, soil samples (0 to 20 cm profile) and plant samples from the fields of pre-dominant cropping systems of each farmer were collected along with GPS coordinates (longitude, latitude, and mean sea level) and analysed using standard methods. Samples of FYM, sulphitation pressmud (SPM), and crop residue were also collected and analysed for total N, P, and K contents. Irrigation water samples collected from different irrigation water sources were analysed for its quality parameters as well as for K and S content (Page et al, 1982).

Surface maps of basic soil properties were prepared using semivariogram parameters through ordinary kriging. Kriged map for each soil property was prepared using ESRI ArcGIS™ 10.1—a geo-statistical analysis tool.

Predominant Cropping Systems and Fertiliser Use Patterns

Farmers' participatory diagnostic surveys reveal that sugarcane-ratoon-wheat is the most predominant cropping system (> 60% acreage) followed by rice-wheat cropping system in WUP. Since dairying is an important enterprise after agriculture in this region, sorghum/pearl millet (fodder)-based systems are also followed. Yields of different crops grown in WUP are fairly high as compared to national and the state averages and fertiliser NPK use varied in accordance with the cropping system, farmers' land holding size, and available resources. On average, small (< 2 ha), medium (2 to 4 ha) and large (> 4 ha) farmers apply 380 to 463 kg N/ha to the sugarcane-ratoon-wheat system, and from 253 to 357 kg N/ha to the rice-wheat system (**Figure 1**). Phosphorus use under different crops grown in the region was sub-optimal, except in the potato-based systems, wherein farmers apply more than double the recommended dose of P (80 kg P_2O_5/ha). Fertiliser K use was restricted to a few crops only such as rice, wheat, sugarcane, mustard, and potato, and a very meagre amount was applied. Highest K use was noticed in the potato-based cropping systems (24 to 75 kg K_2O/ha) followed by the sugarcane-ratoon-wheat system (20 to 30 kg K_2O/ha) and other systems (4 to 32 kg K_2O/ha). Overall, fertiliser use was skewed towards N, whereas nutrients like K, S, and micronutrients were generally neglected. Of the total NPK use, N's share stood at 68 to 71%, indicating that fertiliser management practices of the region are highly imbalanced and may not sustain high productivity in the long run.

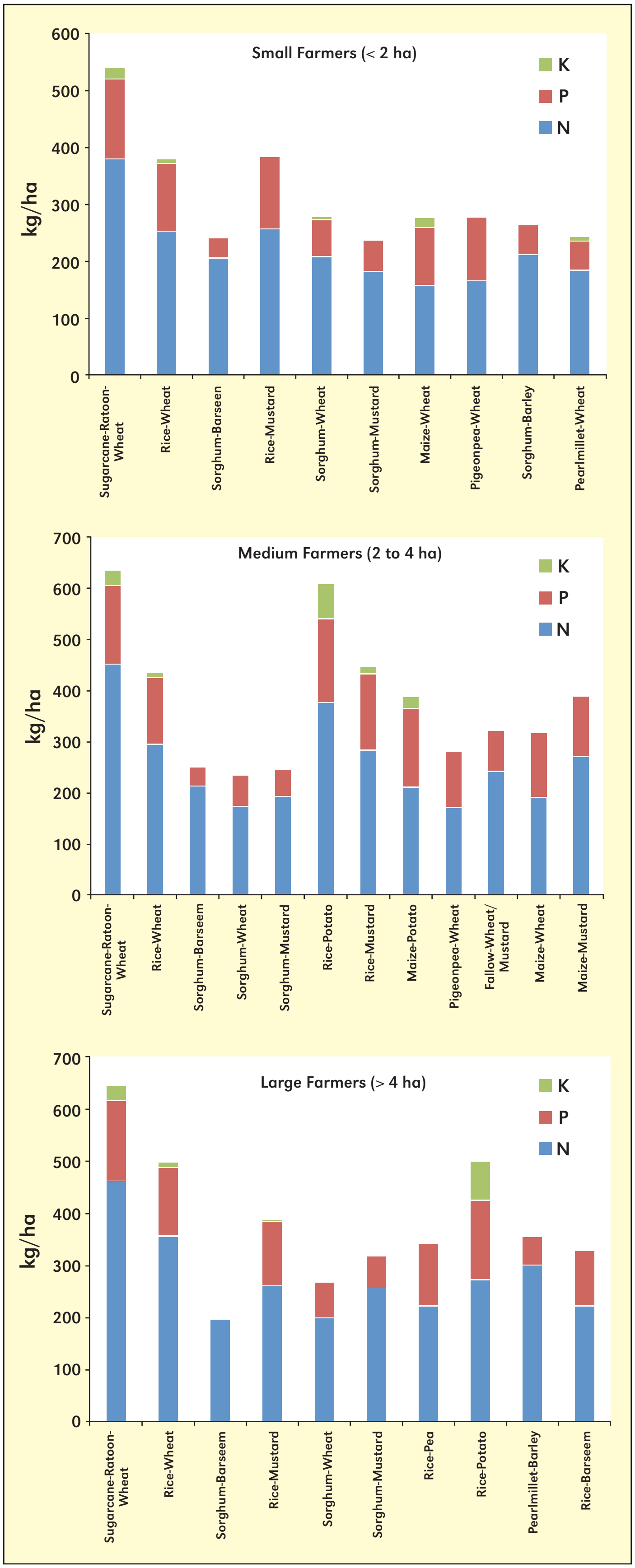

Figure 1. Fertiliser N, P, and K use under different cropping systems of western Uttar Pradesh.

Farmers growing rice, potato, and sugarcane commonly apply Zn as zinc sulphate, while wheat rarely receives direct application of Zn fertiliser. Zinc application allows inadvertent addition of S to the soil, although it is inadequate to meet crop S demand. Direct application of S was rarely noticed. Some medium and large farmers have started preferential use of single superphosphate (SSP 12% S) over DAP in potato and oilseed crops, as they experienced greater benefit with the use of SSP.

Table 1. Use of farmyard manure and its frequency in different crops of western Uttar Pradesh.

	FYM use, t/ha			Frequency, year		Farmers using FYM, %
Crop	Range	Mean	SE±	Range	Mean	
Rice	10-40	27.6	0.0	1-12	3.3	84.8
Wheat	15-35	28.5	0.0	0-10	2.5	24.3
Potato	20-35	25.5	0.2	1-3	1.6	78.6
Sugarcane	10-40	29.9	0.0	1-9	3.4	86.7

Crop Residue Management and Use of Organic Manures

In general, large farmers harvest rice and wheat crops using combine harvesters and burn rice residue in situ, whereas, they remove whole wheat straw after threshing and leave only stubbles (10 to 15% of total residue) in the field. Farmyard manure is the only organic manure used by small farmers, whereas medium and large farmers prefer to use SPM, which they purchase and transport from nearby sugar mills. Farmers apply 25 to 30 t of FYM at 2 to 3 year intervals in crops like rice, wheat, potato, and sugarcane (**Table 1**).

Irrigation Water Quality and Potassium Input through Irrigation

Irrigation water quality was analysed based on samples collected from different sources of irrigation including, tube-

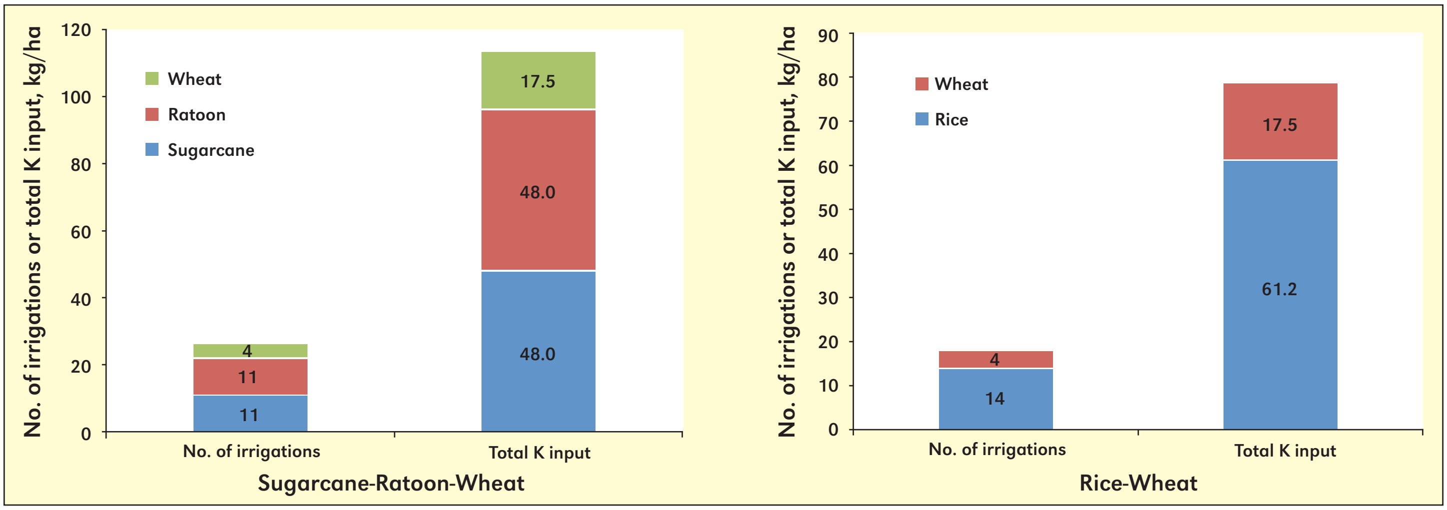

Figure 2. Total number of irrigations and K input through irrigation water under sugarcane-ratoon-wheat and rice-wheat systems in western Uttar Pradesh.

Table 2. Soil organic carbon and NPK status under predominant cropping systems of western Uttar Pradesh.

Cropping system	No. of samples	Min.	Max.	Mean	Samples in range, % Low[b]	Medium[b]	High[b]
			Organic carbon, %				
S-R-W[a]	94	0.32	0.75	0.53	10	90.0	0.0
R-W[a]	83	0.26	0.73	0.48	25	75.0	0.0
S/P/M-Mu/Pt/W[a]	35	0.26	0.67	0.45	0	100	0.0
Over all	212	0.26	0.75	0.49	0	100	0.0
			Available N, kg/ha				
S-R-W	94	77.8	324	168	94.7	5.3	0.0
R-W	83	57.7	309	142	100	0.0	0.0
S/P/M-Mu/Pt/W	35	69.0	332	151	94.3	5.7	0.0
Over all	212	57.7	332	154	96.3	3.7	0.0
			Olsen-P, kg/ha				
S-R-W	94	5.2	35.5	15.0	30.9	63.8	5.3
R-W	83	7.2	30.9	14.8	13.3	75.9	10.8
S/P/M-Mu/Pt/W	35	0.6	29.6	15.8	20.0	77.1	2.9
Over all	212	0.6	35.5	15.2	21.4	72.3	6.3
			Exchangeable K, kg/ha				
S-R-W	94	59.4	728	195	18.1	78.7	3.2
R-W	83	85.1	918	246	8.4	75.9	15.7
S/P/M-Mu/Pt/W	35	54.9	562	240	11.4	74.3	14.3
Over all	212	54.9	918	227	12.6	76.3	11.0
			Available S, mg/kg				
S-R-W	94	4.8	27.0	16.2	19.1	63.8	17.0
R-W	83	7.8	37.2	17.8	22.9	57.8	19.3
S/P/M-Mu/Pt/W	35	8.6	39.3	18.2	22.9	48.6	28.6
Over all	212	4.8	39.3	17.4	21.6	56.7	21.6

[a]S-R-W stands for sugarcane-ratoon-wheat (first predominant cropping system), R-W stands for rice-wheat (second predominant) and S/P/M-Mu/Pt/W stands for sorghum/pearl millet/maize-mustard/potato/wheat (third predominant).
[b]Low, medium, and high ranges for available N ,Olsen P, exchangeable K, and extractable S are < 280 kg, 280 to 560 kg, and > 560 kg N/ha; < 10 kg, 100 to 25 kg, and > 25 kg P/ha; < 130 kg, 130 to 280 kg, and > 280 kg K/ha; < 10 mg/kg, 10 to 20 mg/kg, and > 20 mg/kg S, respectively.

Table 3. Soil micronutrient status under different cropping systems of Western Uttar Pradesh.

Cropping system	No. of samples	Deficient[a]	Sufficient
		DTPA-Zn, %	
S-R-W	93	31	69
R-W	83	39	61
S/P/M-Mu/Pt/W	35	43	57
Over all	211	36	64
		DTPA-Fe, %	
S-R-W	93	16	84
R-W	83	14	86
S/P/M-Mu/Pt/W	35	26	74
Over all	211	17	83
		DTPA-Mn, %	
S-R-W	93	6	94
R-W	83	11	89
S/P/M-Mu/Pt/W	35	17	83
Over all	211	10	90
		DTPA-Cu, %	
S-R-W	93	3	97
R-W	83	10	90
S/P/M-Mu/Pt/W	35	9	91
Over all	211	7	93

[a]Critical limit for Zn, Fe, Mn, and Cu are 0.75 mg/kg, 4.5 mg/kg, 2.0 mg/kg, and 0.2 mg/kg, respectively.

wells, canals, etc. The majority of the samples had neutral reaction and average SAR (1.96) as well as bicarbonate (8.58 me/l), Ca + Mg (7.00 me/l), and K (6.2 ppm) contents. Overall quality of irrigation water in WUP, from a crop production viewpoint, was rated as good. Among the predominant crops grown, rice had maximum K input through irrigation

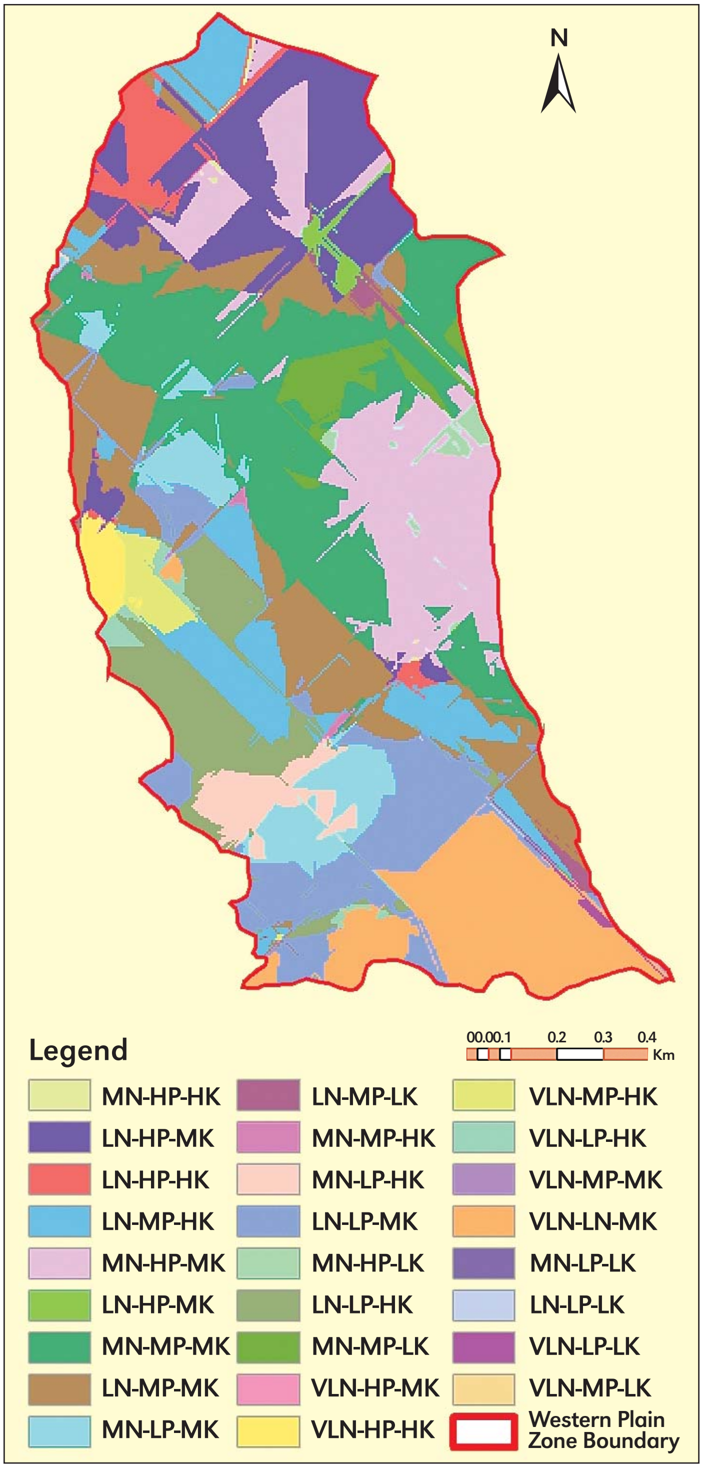

Figure 3. Homogenous Management Zones in western Uttar Pradesh.

water (61 kg K/ha), followed by sugarcane (48 kg K/ha). Potassium input in other crops ranged between 9 to 26 kg/ha only. Highest K recycling through irrigation water was noticed under the sugarcane-ratoon-wheat system (112 kg K/ha) followed by rice-wheat system (79 kg K/ha) (**Figure 2**).

Soil Fertility Status

Different soil fertility parameters, analysed after harvest of crops, varied with the cropping system followed, nutrients used, and agronomic management practices adopted. Soils of WUP fall under low-to-medium category (< 0.75%) of organic C content (**Table 2**). Averaged across the cropping system and locations, 96%, 21%, 13%, and 22% of soils were low and 4%, 72%, 76%, and 57% of soils were under medium category for N (< 280 kg/ha), P (< 10 kg/ha), K (< 130 kg/ha), and S (< 10 mg/kg) contents. In these soils, responses to fertiliser application can be expected.

Analysis of micronutrients (i.e., DTPA extractable-Zn, Fe, Mn, and Cu in the different cropping systems indicated a varying degree of deficiencies (**Table 3**). Using a threshold of 0.6 mg/kg soil Zn, highest Zn deficiency was found in soils under the sorghum/pearl millet/maize-mustard/potato/wheat system, followed by the rice-wheat system, and the sugarcane-ratoon-wheat system. Iron deficiency in different cropping systems across WUP was 17% based on threshold of 4.5 mg/kg DTPA-Fe. The magnitudes of Mn and Cu deficiencies were smaller than Zn and Fe deficiencies.

In order to generate homogenous fertility management zones, different fertility parameters were classified into low, medium, and high categories by user-defined ranges. The ranges used for classification within low, medium, and high classes were (kg/ha): N < 120, 120 to 160 and > 160; P <13, 13 to 16 and > 16; and K <150, 150 to 250 and > 250, respectively. Based on the developed homogenous fertility zones (**Figure 3**), fertiliser recommendations can be developed for these zones.

Summary

Wide variations in the fertiliser use patterns were revealed under predominant cropping systems in the WUP through farmers' participatory surveys on nutrient management practices. Generally, fertiliser use was skewed in favour of N, whereas nutrients like K, S, and micronutrients were neglected. Based on different soil fertility parameters, predicted surface maps were generated and homogenous fertility management zones were developed. BC-SA

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Managing Fertiliser Nitrogen to Optimise Yield and Economics of Maize-Wheat Cropping System in Northern Karnataka

By D.P. Biradar, Y.R. Aladakatti, D. Shivamurthy, T. Satyanarayana, and K. Majumdar

Farmers in northern Karnataka apply very high doses of fertiliser N to maize-wheat cropping system to maintain the yields of both the crops. This study attempted to estimate right rate and time of N application for improving the yield and profitability of maize-wheat system.

After rice, wheat and maize are the two major cereals contributing to food security and farm income in India. Maize is steadily becoming an important option for diversifying agricultural production owing to its growing demand for human, dairy, and poultry consumption, and its increasing use in pharmaceuticals and other allied industries. Maize-based cropping systems are gaining significance in India, and maize-wheat is an important cropping system occupying about 1.8 million (M) ha in the country (Timsina et al., 2010). In Karnataka, maize is grown on about 1 M ha with a production of about 3.6 M t and an average productivity of 3.1 t/ha; while wheat is grown on about 0.3 M ha with a production of about 0.23 M t (Anonymous, 2010).

High yielding MWCS extract large amounts of mineral nutrients from the soil and proper nutrient management should aim to supply fertilisers adequate to meet the requirement of both crops. Much information on the source, rate, method, and time of N application in India is available for the individual maize and wheat crops, rather than for the system as a whole. Nitrogen plays an important role in the MWCS and applying right rates of N at the right time, through split application matching stages of high physiological N demand, is critical to achieve higher yields. However, current official recommendations for N use in the MWCS of Northern Karnataka is generally based on fixed rates and timing of application (blanket recommendation), which is not sufficient to harness the yield potential of hybrid genotypes of maize and leads to low N use efficiency. Also, farmers in this region do not apply N in the right rate at the right time and generally use higher doses of N in order to sustain the yields of previous years. Improved N management using the LCC has consistently shown to increase yield and profit as compared to FFP (Rajendran et al., 2010). We designed a study to develop schedules for the right rate and time of N application in MWCS of northern Karnataka.

The experimental site was located at the main agricultural research station of the University of Agricultural Sciences in Dharwad, Karnataka. Field experiments were conducted on a fixed site for three consecutive years (from 2009-10 to 2011-12) during *kharif* and *rabi* seasons to assess the effect of N rate, time of application, and real-time N management using LCC on productivity of *maize-wheat* cropping system. The soil of the experimental field was slightly alkaline (pH 7.4) and 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 (208 kg/ha), high (35 kg/ha), and high (350 kg/ha), respectively and available contents of secondary and micronutrients were adequate. The experiment was laid out in a split-plot design. Maize was grown during the rainy season (*kharif*), with four N levels (0, 80, 160, and 240 kg N/ha) and three N application timings including: T_1 (33% basal + 33% at V_4 to V_6 growth stages + 33% at V_{10} stage), T_2 (same as T_1 but N application guided by LCC use), and T_3 (50% basal + 50% at V_{10} stage). Cargill M-900 was the maize hybrid used in the study with a planting geometry of 60 x 20 cm. Similarly, wheat was grown during winter season (*rabi*), with four N levels (0, 50, 100, 150 kg N/ha), and three timings including: T_1 (33% as basal + 33% at crown root initiation (CRI) + 33% at Panicle Initiation), T_2 (same as T_1 but N application guided by LCC use), and T_3 (50% as basal + 50% at CRI). The treatments were replicated thrice with a common dose of P_2O_5 and K_2O (each 100 kg/ha) for maize and 90 kg P_2O_5/ha and 80 kg K_2O/ha for wheat. DWR-162 was the wheat variety used with a spacing of 25 x 10 cm.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; EC = electrical conductivity; MWCS = maize-wheat cropping system; LCC = Leaf colour chart; FFP = Farmer Fertiliser Practice; CRI = crown root initiation; PI = panicle initiation; MEqY = maize equivalent yield of wheat; B:C ratio = benefit to cost ratio; AE_N = agronomic efficiency of N; ROI = return on investment.

Visiting IPNI supported research on site-specific nutrient management in maize-wheat cropping. (Standing from L to R are Mr. D. Sivamurthy, Dr. T. Satyanarayana, Dr. D.P. Biradar, and Dr. Y.R. Aladakatti.

LCC-based, real time N-management included monitoring leaf colour at weekly intervals during the crop-growing season. Nitrogen was applied whenever leaves were less green than a threshold LCC value, which corresponds to a critical leaf N-content. Uniform cultural practices and plant protection measures were adopted in all treatments. Yield observations were recorded in all the treatments for both the crops, and the average of three years data is reported in this paper. System productivity (in terms of maize equivalent yield) is reported, which was calculated as:

Table 1. Effect of rate and time of nitrogen application on yield of maize and wheat crops (mean of three years, 2009-10 to 2011-12).

	Maize				Wheat			
Treatments	Grain yield, kg/ha	Stover yield, kg/ha	Harvest Index	100 seed weight, g	Grain yield, kg/ha	Straw yield, kg/ha	Harvest Index	100 seed weight, g
Main plots (N rate)								
N_1	1,578	4,067	0.28	25.1	1,373	2,470	0.36	5.33
N_2	4,123	6,286	0.40	30.2	2,515	4,320	0.37	6.33
N_3	6,196	7,940	0.44	31.3	3,331	5,876	0.36	6.66
N_4	6,950	9,073	0.43	33.3	3,781	6,942	0.35	6.88
SEm±	98	120	0.04	0.6	44	42	0.003	0.36
C.D. (5%)	338	416	0.03	1.9	152	145	0.01	NS
Sub plots (Time of Application)								
T_1	4,838	7,033	0.41	30.4	2,793	4,947	0.36	6.33
T_2	4,978	7,122	0.41	30.8	2,827	4,959	0.36	6.67
T_3	4,320	6,370	0.40	28.8	2,630	4,801	0.35	5.92
SEm±	63	102	0.002	0.6	46	61	0.003	0.21
C.D. (5%)	187	307	NS	NS	138	NS	NS	NS
Interaction	*	NS	NS	NS	NS	NS	NS	NS

MEqY = [(kg yield of wheat crop in maize based system x unit price of wheat)/unit price of maize) + actual maize yield].

We also calculated gross return, net return and B:C ratio using maize and wheat prices during the experimental year.

Results

Increasing levels of N application led to increases in grain yield, stover yield, harvest index and test weight of both maize and wheat crops (**Table 1**). Interestingly, this trend persisted during all the three years of this study. Application of N in three splits with and without the use of LCC resulted in significantly higher maize and wheat yields than those obtained with N application in two splits. Except for the grain yield of maize, the interaction effects of N rate and time of application with respect to other parameters were non-significant for both crops. Harvest index and 100 seed weight for both maize and wheat crops did not differ significantly with rate and time of N application.

Economic analysis of data followed a similar trend to grain yields of maize and wheat crops with significant increases in gross and net returns as well as in B:C ratios with increasing levels of N application and with three splits of N application with and without the use of LCC (**Table 2**). However, a significant interaction effect of N rate and time existed for all the three economic parameters measured for maize, while the same did not exist in wheat.

Calculation of system productivity showed a significantly higher grain yield, net returns, and B:C ratios of maize-wheat system with increasing levels of N (**Table 3**). These findings are in line with Gill et al. (2009), who reported a system productivity of 9,122 kg/ha and a total net return of Rs 52,842/ha for the MWCS. Yield responses to applications of 390, 260, and 130 kg N/ha were 9,017, 7,585, and 4,274 kg/ha, respectively, over the no-N treatment.

Even though the yield increase due to N fertilisation was substantial (248% at 390 kg N/ha and 118% at 130 kg N/ha), the AE_N (kg grain/kg N) decreased from 32.9 to 23.1 with increasing N rates from 130 to 390 kg N/ha (**Table 4**). This indicated lower N use efficiencies at higher N application rates. Also, with increasing N rates, ROI for N fertiliser in the MWCS, decreased from 20.4 to 12.7 with a mean return of 16.6 Rs/Re invested. The results indicated that although the net returns increased with increasing N rates, but they also came at the cost of increased risk level for the farmer. Therefore, in addition to crop response, AE_N and ROI also need to be considered while deciding on the N application rate in the MWCS. Further, the information on crop yield response to N fertiliser application helps to improve crop yields through the use of nutrients at the right rate and time. This helps to effectively manage escalating fertiliser price scenarios. Relatively better AEN (30.7) and ROI (17.7) noticed with N application in three splits using LCC indicated the right time of N application in maize-wheat cropping system.

Table 2. Effect of rate and time of nitrogen application on economics of maize and wheat crops (mean of three years, 2009-10 to 2011-12).

	Maize			Wheat		
Treatments	Gross returns, Rs/ha	Net returns, Rs/ha	B:C ratio	Gross returns, Rs/ha	Net returns, Rs/ha	B:C ratio
N_1	15,841	4,986	1.45	18,018	6,648	1.87
N_2	39,444	25,927	2.91	33,402	20,186	2.89
N_3	58,710	42,863	3.69	44,464	30,488	3.54
N_4	65,915	48,660	3.81	50,450	35,884	3.82
SEm±	892	824	0.04	571	545	0.05
C.D. (5%)	3,086	2,851	0.15	1,975	1,887	0.16
T_1	46,203	31,746	3.02	37,158	23,825	3.07
T_2	47,458	32,904	3.08	37,599	24,249	3.10
T_3	41,271	27,177	2.79	34,993	21,831	2.93
SEm±	568	525	0.03	592	565	0.05
C.D. (5%)	1,702	1,572	0.08	1,774	1,692	NS
Interaction	*	*	*	NS	NS	NS

Conclusion

Application of N at 390 kg/ha resulted in higher maize-wheat yields and higher net returns than other treatments. Thus, applying the right rate of N (240 and 150 kg/ha in maize and wheat), coupled with the right timing for N fertiliser (i.e. 3-split applications) using LCC-based real time

Table 3. Effect of rate and time of N application on yield and economics of maize-wheat cropping system (mean of three years, 2009-10 to 2011-12).

	System yield, kg/ha (Maize yield + MEqY of wheat)				Net returns, Rs/ha				B:C Ratio			
Treatment	T_1	T_2	T_3	Mean	T_1	T_2	T_3	Mean	T_1	T_2	T_3	Mean
N_1	3,683	3,609	3,608	3,634	8,542	7,936	7,927	8,135	1.37	1.35	1.35	1.36
N_2	8,113	8,270	7,340	7,908	41,338	42,580	35,341	39,753	2.5	2.54	2.31	2.45
N_3	11,534	11,898	10,224	11,219	67,033	69,906	56,752	64,564	3.16	3.24	2.88	3.09
N_4	12,842	13,158	11,954	12,651	75,984	78,494	69,114	74,531	3.29	3.35	3.12	3.25
Mean	9,043	9,234	8,282		48,224	49,729	42,284		2.58	2.62	2.42	

	SEm±	C.D. (5%)	S.Em±	C.D. (5%)	S.Em±	C.D. (5%)
Main plot	103	359	817	2,830	0.024	0.082
Sub plot	103	309	821	2,462	0.026	0.079
Interaction	206	618	1,643	4,924	0.053	0.158

N management proved to be beneficial in increasing the yield and profitability of maize-wheat farmers of northern Karnataka. Under the increasing price scenario of fertilisers, a wise decision on fertiliser application must consider the crop yield response to N fertiliser application and its associated AE_N and ROI to match the socio-economic condition of the farmer. BC-SA

Table 4. Interaction effect of nitrogen rate, time of application and real-time N management on agronomic efficiency of N (AEN) and return on investment (ROI) under maize-wheat system (mean of three years, 2009-10 to 2011-12).

	AEN, kg grain increase/kg N				ROI, Rs/Re invested in N			
Treatment	T_1	T_2	T_3	Mean	T_1	T_2	T_3	Mean
N_1	–	–	–	–	–	–	–	–
N_2	34.07	35.85	28.71	32.88	21.20	21.84	18.12	20.39
N_3	30.19	31.88	25.45	29.17	17.19	17.92	14.55	16.55
N_4	23.48	24.48	21.40	23.12	12.99	13.42	11.81	12.74
Mean	29.25	30.74	25.18	28.39	17.13	17.73	14.83	16.56

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Videos Available from IPNI South Asia Program

A significant part of IPNI's global mandate includes disseminating appropriate crop nutrient management information/ knowledge through printed and audio-visual medium. IPNI South Asia Program staff has been active in developing crop and nutrient specific videos for extension purpose. Developed in regional languages, these simple videos are expected to help industry as well as other stakeholder extension systems to convey simple messages about the importance of specific nutrients as a part of balanced fertilisation or the right ways of managing nutrients for specific crops for higher yields, farmer profitability and better environmental stewardship of nutrients. A video on the importance of Potassium in Crop Production, made in Hindi, is now also available in Bengali, Oriya, and Telegu regional languages. A Hindi video on nutrient management in sugarcane and a Telegu video on nutrient management in cotton were also developed through the support of fertiliser industry and the cooperators from the National Agricultural Research System. These two videos are also available in Oriya language. BC-SA

Nutrient Responses and Economics of Nutrient Use in Pearl Millet under Semi-Arid Conditions

By Vinay Singh and K. Majumdar

On-farm omission plot experiments with pearl millet in the semi-arid region of Uttar Pradesh showed a large variation in yield and nutrient responses among farmers' fields. Balanced nutrient application improved pearl millet yield, nutrient uptake, economic efficiency, crop productivity, partial factor productivity, net returns and B:C ratio.

Pearl millet (*Pennisetum glaucum* L) or *bajra* is an important crop of the rainfed region of India and is grown on about 8.9 M ha (FAI, 2010-11). The annual production is about 6.5 M t or 3% of the total food grain output in India. Most of the pearl millet is grown under dryland (non-irrigated) conditions and on poor to marginal soils with little or no fertiliser application. Thus, the national average productivity of pearl millet is only 731 kg/ha (FAI, 2010-11). From a quality point of view, pearl millet grain is rich in minerals (2.0 to 3.5%) and fat content (4.0 to 8.0%). It is a high protein grain (10.5 to 14.5%) with high levels of essential amino acids (Gautam, 2005). Pearl millet provides food and nutritional security to many poor farming communities in the country. The major pearl millet-growing states in India are Rajasthan (5.2 M ha), Maharashtra (1.03 M ha), Uttar Pradesh (0.85 M ha), Gujarat (0.67 M ha), Haryana (0.60 M ha), and Karnataka (0.31 M ha). Among these states, Uttar Pradesh has the highest productivity (1,638 kg/ha) of this crop followed closely by Haryana (1,593 kg/ha). Pearl millet-wheat is an important crop sequence in Agra region of Uttar Pradesh. Both these crops have been reported to deplete the soil fertility to a great extent. Pearl millet-wheat sequence removes 276 kg N, 42 kg P_2O_5, and 264 kg K_2O/ha, often exceeding the applied nutrients. Fertiliser management in this area is confined primarily to the application of N and P fertilisers. Very little or no K is being applied by farmers to pearl millet, and thus most of the K taken up by the crop comes from K reserves of the soil. Continuous cropping without K application has been reported to cause considerable yield losses in pearl millet and wheat (Dwivedi et al., 2011). Farmers are indeed experiencing declining responses to N and P due to omission of other essential nutrients in their fertiliser schedules. We hypothesised that the adoption of balanced and judicious use of all needed nutrients can help improve the productivity of pearl millet.

Fertiliser constitutes one of the costliest inputs in present day agriculture. Efficient management of plant nutrients through fertiliser best management practices can ensure that fertilisers are used economically while the crops are supplied with all essential plant nutrients at the appropriate time and in the required quantity. Proper understanding of soil nutrient supplying capacity is, therefore, essential for efficient management of fertilisers. The current study was initiated to: (a) estimate indigenous nutrient supplying capacity of the soils in Agra district of Uttar Pradesh through a plant-based approach, and (b) assess yield and economic losses in pearl millet associated with omission of N, P, K, and S from the fertilisation schedule.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; C = carbon; B:C = benefit:cost ratio.

Dr. Vinay Singh (left) inspects pearl millet nutrient omission plots at an on-farm field day held in Agra district, Uttar Pradesh.

On-farm experiments were conducted at four different locations, viz., Artoni, Panwari, Nanpur, and Sahara villages (four farmers' fields in each village) of Agra district of Uttar Pradesh, for 2010 and 2011. The area is characterised by a semi-arid, hot summer climate with mean maximum temperature of 45°C and mean minimum temperature of around 3°C in December-January. The average annual rainfall in the study area is 650 mm of which about 90% is received during *kharif* seasons from July to September and rest during the *rabi* season. The important characteristics of soils (0 to 15 cm) at the four locations are given in **Table 1**.

Treatments consisted of ample NPKS, N omission, P omission, K omission, and S omission plots in a randomised block design. The nutrient rates used in the ample NPKS treatment was 120 kg N, 70 kg P_2O_5, 100 kg K_2O, and 30 kg S/ha. In the ample NPKS treatment, all nutrients were applied in excess of actual requirement of pearl millet following the omission plot experiment protocol. Nutrients were subsequently omitted from the ample NPKS treatment for the omission treatments.

Table 1. Soil characteristics of the experimental fields (mean of four farmer fields at each site).

Soil characteristics	Artoni	Panwari	Nanpur	Sahara
pH (1:2.5 soil:water suspension)	7.70	7.60	8.00	8.10
EC, dS/m	0.21	0.30	0.27	0.33
Organic C, g/kg	3.90	3.70	3.80	3.90
Available N, kg/ha	178	161	161	164
Available P, kg/ha	12.1	10.7	12.7	11.3
Available K, kg/ha	132	124	130	129
Available S, kg/ha	16.8	12.2	15.7	14.7

Hybrid pearl millet (var. Mahyco 2210) was sown in July and harvested in last week of September in both experimental years. Urea, diammonium phosphate, muriate of potash, and elemental S were used as sources for N, P, K and S, respectively. Phosphorus was applied as single superphosphate in the N omission treatment. The plot size at different locations was approximately 500 m^2 except for N omission treatment (approximately 100 m^2). Each farmer field was treated as a replication for statistical analysis of the results. At harvest, yield data of the crop (grain and straw) were recorded. Nutrient contents in grain and straw and available nutrients in soils were determined using standard methods. Uptake of nutrients was calculated by multiplying nutrient content in grain and straw with their respective yields.

Results

Average yields in ample NPKS, N omission, P omission, K omission and S omission plots were 4,103, 2,770, 3,286, 3,743, and 3,948 kg/ha, respectively (**Figure 1**). Yield responses across sites and years varied considerably with an average of 1,333, 816, 359, and 155 kg/ha for N, P, K, and S, respectively. Significantly lower pearl millet grain and straw yields were recorded in N omission treatment plots at all the experimental sites as compared to any other treatments (**Table 2**). In the P omitted treatment, pearl millet grain yield exhibited a significant decrease of 860, 773, 835, and 805 kg/ha at Artoni, Panwari, Nanpur, and Sahara, respectively, over the NPKS (T_1) treatment. The corresponding mean reductions in grain yield due to K omission treatment were 8.2, 8.3, 8.5, and 10.2% of the ample nutrient treatment. The reduction in grain yield due to S omission at different sites ranged from 3.0 to 5.1%. The mean grain yields of pearl millet reduced by 32.5, 19.9, 8.8, and 3.8% due to N, P, K, and S omissions across locations, respectively. Application of NPK fertiliser with S (T_1) resulted in highest pearl millet grain yield at all the experimental sites indicating a synergistic relationship of NPK with S. Similar results were earlier reported by Dwivedi et al. (2011).

The gross returns worked out by considering current cost of nutrients and minimum support price (MSP) of pearl millet increased from Rs 26,716 to 40,066, Rs 27,726 to 39,618, Rs 26,023 to 39,631, and Rs 26,630 to 40,172 at Artoni, Panwari, Nanpur, and Sahara, respectively, in plots receiving NPKS (T_1) over N omission (-N) treatment. A comparison of net returns and benefit cost ratio (B:C) for different treatments in pearl millet revealed the economic benefit of applying NPKS fertilisers. There was a maximum mean net profit of Rs 25,561/ha in pearl millet with NPKS application. A minimum net profit of Rs 13,767 per ha was recorded under N omission treatment (**Table 2**). Among the sites, the maximum net

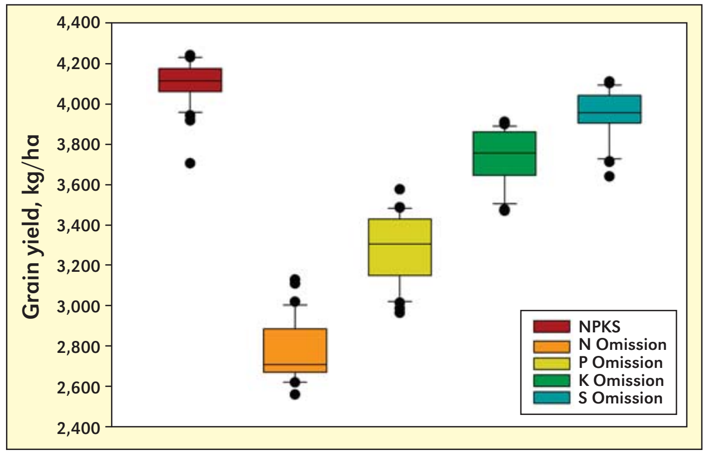

Figure 1. Grain yield of pearl millet in various treatments at farmers' fields. The error bars represent 10th to 90th percentile of the data.

Table 2. Yield and economics of pearl millet grown in farmers' fields (mean of two years, 2010 and 2011).

Treatments	Grain yield, kg/ha	Straw yield, kg/ha	Yield difference, kg/ha	Gross return, Rs/ha	Net return, Rs/ha	B:C Ratio
Artoni, Site 1 (n=4*)						
T_1 (NPKS)	4,122	8,130		40,066	25,454	1.75
T_2 (–N)	2,770	5,320	1,352 (32.8)	26,716	13,718	1.06
T_3 (–P)	3,262	6,153	860 (20.9)	31,453	18,298	1.39
T_4 (–K)	3,784	7,273	338 (8.2)	33,617	22,727	1.64
T_5 (–S)	3,913	7,658	209 (5.1)	37,998	24,386	1.80
C.D. (p=0.05)	100.0	188.0	-	-	-	-
Panwari, Site 2 (n=4)						
T_1 (NPKS)	4,078	8,031		39,618	24,981	1.71
T_2 (–N)	2,866	5,494	1,212 (29.7)	27,726	14,717	1.13
T_3 (–P)	3,305	6,196	773 (18.9)	32,077	18,836	1.45
T_4 (–K)	3,741	7,063	337 (8.3)	36,135	22,245	1.61
T_5 (–S)	3,957	7,757	121 (3.0)	38,404	24,792	1.84
C.D. (p=0.05)	95.0	182.0	-	-	-	-
Nanpur, Site 3 (n=4)						
T_1 (NPKS)	4,077	8,066		39,631	25,020	1.71
T_2 (–N)	2,688	5,189	1,390 (34.1)	26,023	13,013	1.00
T_3 (–P)	3,242	6,248	835 (20.5)	31,307	18,154	1.38
T_4 (–K)	3,730	7,154	348 (8.5)	36,056	22,167	1.60
T_5 (–S)	3,954	7,678	122 (3.0)	38,315	24,703	1.83
C.D. (p=0.05)	91.5	185.6	-	-	-	-
Sahara, Site 4 (n=4)						
T_1 (NPKS)	4,140	8,094		40,172	25,561	1.75
T_2 (–N)	2,756	5,276	1,384 (33.4)	26,630	13,620	1.05
T_3 (–P)	3,335	6,418	805 (19.4)	32,228	19,074	1.45
T_4 (–K)	3,719	7,032	421 (10.2)	35,865	21,976	1.58
T_5 (–S)	3,966	7,858	174 (4.2)	38,458	24,846	1.84
C.D. (p=0.05)	97.0	190.0	-	-	-	-

*n = number of farmer fields in each site. Values in parentheses are percent decline in yield relative to the NPKS treatment.

Table 3. Total uptake of nutrients (kg/ha) by pearl millet (mean of two years, 2010-11).

Treatments	Pearl millet N	P	K	S
Artoni, Site 1 (n=4*)				
T_1 (NPKS)	115	18.2	210	19.0
T_2 (-N)	67.7	11.1	163	10.3
T_3 (-P)	85.7	11.6	160	11.7
T_4 (-K)	101	14.9	170	14.6
T_5 (-S)	103	16.5	199	13.8
C.D. (p=0.05)	2.40	0.59	6.25	2.22
Panwari, Site 2 (n=4)				
T_1 (NPKS)	114	17.9	208	19.2
T_2 (-N)	69.8	11.3	140	10.4
T_3 (-P)	83.3	11.1	161	12.0
T_4 (-K)	99.8	14.7	167	14.8
T_5 (-S)	103	16.4	202	14.5
C.D. (p=0.05)	2.31	0.64	6.22	2.17
Nanpur, Site 3 (n=4)				
T_1 (NPKS)	114	18.0	208	18.7
T_2 (-N)	65.6	10.9	133	10.1
T_3 (-P)	85.8	11.5	161	11.9
T_4 (-K)	99.6	14.5	167	14.7
T_5 (-S)	103	17.0	200	14.3
C.D. (p=0.05)	2.61	0.67	6.40	2.09
Sahara, Site 4 (n=4)				
T_1 (NPKS)	115	17.9	209	19.3
T_2 (-N)	70.1	10.8	135	10.2
T_3 (-P)	87.8	11.4	166	12.1
T_4 (-K)	98.9	14.3	166	15.2
T_5 (-S)	101	16.4	204	14.8
C.D. (p=0.05)	2.25	0.55	6.14	2.11

*n = number of farmer fields in each site.

profit was obtained at site IV under ample NPKS treatment. The minimum net profit and B:C ratios were recorded under N omission treatment at site III.

Nutrient uptake followed trends similar to those observed for grain and stover yields (**Table 3**). The total uptake of nutrients was significantly influenced by the balanced application of nutrients. The maximum total uptake of N (114 to 115 kg/ha), P (17.9 to 18.2 kg/ha), K (208 to 210 kg/ha), and S (18.7 to 19.3 kg/ha) was recorded with the T_1 (NPKS) treatment, respectively. It was due to the fact that added nutrients increased the N, P, K, and S content in grain and straw of the crops due to no limitation of nutrients, which resulted in more uptake and higher yields. The highest average yield of 4.1 t/ha was obtained at a removal of 18 kg N, 2.1 kg P, 6.3 kg K, and 2 kg S per t of pearl millet grain yield. By comparison, the total uptake of nutrients under nutrient omission treatments decreased considerably, which suggests that limitation of one nutrient in the soil affects the uptake of other nutrients, again highlighting the importance of balanced fertilisation to crops. In general, the lowest total uptakes of N, P, K, and S were recorded under treatments omitting N, P, K, and S, respectively.

Summary

Results from our on-farm experiments clearly showed that N is the most limiting nutrient in the study area, followed by P, K, and S. The responses of nutrients varied widely across farmers' fields and years, which emphasised the need for site-specific nutrient management based on indigenous nutrient supply, yield target, and realistic estimation of achievable nutrient use efficiencies. Inadequate or no application of any limiting nutrient would reduce pearl millet yield and adversely affect the uptake and utilisation of other amply provided nutrients, further reducing yields. Balanced application of nutrients could double pearl millet yields from the current value with consequent increase in farmer profits. BC-SA

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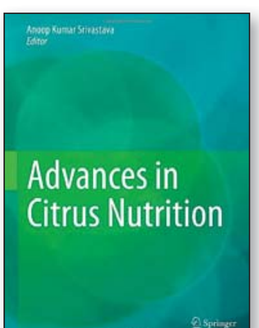
New Book: Advances in Citrus Nutrition by Dr. A.K. Srivastava



Despite many breakthroughs in the diagnosis and management of nutrient constraints, citrus nutritionists are still baffled by the complex processes associated with precise field diagnosis of different nutrient constraints. Currently available diagnostic tools are more applicable to next season's crop, instead of addressing the constraints in the current standing crop. However, there have been some distinctive developments in the recent past that appear to be quite promising in addressing these constraints. These developments include the application of geospatial tools including non-destructive proximal sensing, metalloenzymes through increasing involvement of genomics and metabolomics (e.g. expressed tag analysis), exploiting the dynamic relationship between soil enzymes and fertility variations etc. This book is a maiden effort to consolidate the information related to different aspects of citrus nutrition in a holistic manner. The book has 30 chapters written by 72 eminent researchers from 19 different countries and has been published by Springer-Verlag, Netherlands.

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Improved Nutrient Management in Rice-Maize Cropping Systems: A Case Study

By J. Timsina and K. Majumdar

On-farm variability in maize yield responses and agronomic efficiencies of N, P, and K across three districts in Bangladesh were evaluated. The results support the adoption of a site-specific nutrient management approach to tackle the challenge of stagnating or declining maize yields in Bangladesh.

Maize is commonly grown in Bangladesh in a rice-maize (R-M) system, and maize yields in Bangladesh are currently among the highest in the tropics (Timsina et al., 2010, 2011). However, signs of stagnation and decline in maize yields have started to emerge in the last few years. This has led to rising concerns that continuous production of high yielding maize will lead to a depletion of mineral nutrients from soils. Soil nutrient depletion is often accelerated with maize versus rice or wheat because of the higher biomass production, greater nutrient requirements, and increased nutrient removal by the maize crop. Many farmers, however, mostly apply unbalanced fertilisers, particularly low amounts of P, K, S and other micronutrients. In a R-M experiment, Ali et al. (2009) found highly negative nutrient balance for N and K (-120 to -134 and -80 to -109 kg/ha, respectively) but a positive balance for P (15 to 33 kg/ha). There are indications that grain yields have been decreasing where maize has been grown on the same land for the last 5 to 10 years. Thus, there is a need to understand nutrient related constraints affecting maize yields in Bangladesh. Also, given the complexity of the R-M system, through it's anaerobic-aerobic cycles, it is important to understand both nutrient balance and nutrient use efficiency under the existing practices, and how these practices could be improved to maintain sustainability of this cropping system.

This case study shows results from an on-farm trial in 2009-10 with *rabi* maize grown in three districts/sites (Comilla [12 farms], Rajshahi [9 farms], and Rangpur [4 farms]) of Bangladesh to demonstrate attainable yield of maize, agronomic response, and nutrient use efficiencies in farmer fields across the three districts. The experiment had the following treatments: -N (no N), -P (no P), -K (no K), NPK, NK with low dose of P (low P), NP with low dose of K (low K), and N with low doses of P and K (low PK). The N, P_2O_5, and K_2O rates used in the full NPK treatment were 240, 170, and 240 kg/ha, respectively. The low P and low K rates were 100 and 170 kg/ha of P_2O_5 and K_2O, respectively.

Soils in Comilla and Rangpur were acidic (pH 5.6), while in Rajshahi they were slightly alkaline (pH 7.6). Organic C was higher in Rajshahi (0.88%) than in the other two districts (0.75 to 0.78%). Soil total N in all districts was quite low with 0.1% in Comilla and 0.06% in the other two districts. Available P content in all the three districts was higher (27 to 47 mg/kg) than the critical level of 14 mg/kg. Exchangeable soil K concentrations in Comilla and Rajshahi were 0.15 and 0.19 cmol/kg, which were more than the critical level of 0.1 cmol/kg for lowland rice, but were less than the critical level of 0.2 cmol/kg for upland crops such as maize, while in Rangpur, the soil K concentration was higher (0.32 cmol/kg) than the critical value.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; C = Carbon; AE_N = agronomic efficiency of nitrogen; AE_P = agronomic efficiency of phosphorus; AE_K = agronomic efficiency of potassium.

Dr. Timsina (left) **and Dr. Majumdar** (second from far right) along with cooperating farmers.

Results

Maize grain yields in all treatments varied considerably across the three sites (**Table 1**). Omission of K decreased maize yield significantly more than the omission of P at Comilla, while the opposite was true for Rajshahi and Rangpur sites. At Rajshahi, either low P or low K applications reduced maize yields significantly, while at all the three sites omission of any of the three nutrients reduced maize yields significantly. Omission of N reduced maize yields more in Rangpur, while omission of K had more pronounced effect in Comilla than at other sites. Reduced yield in K-omitted or low-K plots at Comilla and Rajshahi was due to inherently low soil K at these sites.

Table 1. Effect of nutrient omission/reduction from an ample NPK treatment on grain yield of rabi maize in 2009-10 at three locations in Bangladesh.

	- - - - - Grain yield, t/ha - - - - -		
Treatment	Comilla (n = 12)	Rajshahi (n = 9)	Rangpur (n = 4)
-N	5.9	6.6	4.2
-P	7.3	7.4	6.6
-K	5.1	7.8	7.1
NPK	8.7	9.3	8.1
NK and low P	8.3	8.2	7.4
NP and low K	8.1	8.5	7.5
N low PK	7.9	8.8	6.9
LSD (p = 0.05)	0.97	0.64	1.15
CV (%)	16.3	8.4	11.3

At Comilla, maize responded to N and K applications better than to P application (**Table 2**). Yield

Farmers preparing the maize planter for their field trials.

Table 2. Number of farmers' fields showing yield response to N, P, and K in three districts of Bangladesh in 2009-10.

Yield gain, t/ha	--- Comilla ---			--- Rajshahi ---			--- Rangpur ---		
	N	P	K	N	P	K	N	P	K
< 1	3	4	1	1	1	3	0	1	2
1 to 2	2	4	3	3	6	4	0	3	1
2 to 3	3	4	0	2	1	1	0	0	1
3 to 4	1	0	2	0	0	1	3	0	0
4 to 5	2	0	2	2	1	0	1	0	0
> 5	1	0	4	1	0	0	0	0	0

gain due to K application was > 5 t/ha in 4 of the 12 farmer fields at this site. In Rajshahi, maize responded to all three nutrient (NPK) applications, while in Rangpur, N seemed to have a more significant effect on maize yields.

Grain yields in N, P, and K omission plots were not well correlated with the native soil N, P, and K contents, respectively (data not shown). Soil N content across the three sites varied from less than 0.03 to 0.13%, and the grain yield in -N plots varied from 3 to 8 t/ha. But soil N showed poor correlation with the yield of maize in N omission plots across sites. Similar results were obtained for P and K where soil available P and soil test K poorly explained maize yields in the -P and -K treatment plots.

The agronomic use efficiencies for N, P, and K in maize varied widely across districts as well as across farmer fields within a district (**Table 3**). The maximum AE_N observed in Comilla, Rajshahi, and Rangpur were 28.2, 20.5, and 18.2 kg grain/kg N, respectively, which represents a "reasonable" value for soils containing about 1% organic C. However, the mean and median of AE_N in all the three districts was poor. The maximum AE_P was observed in Rajshahi, while the maximum AE_K was observed in Comilla. The results corroborated well with the yield responses to P and K at these two sites.

Given the large variability in yield responses of N, P, and K across locations and deficient grain content of these nutrients in all sites, a site-specific nutrient management strategy

Table 3. Agronomic use efficiencies of N (AE_N), P (AE_P), and K (AE_K) in rabi maize grown in three districts of Bangladesh in 2009-10.

Attribute	Minimum	Maximum	Mean	Median
Comilla (n = 12)				
AE_N, kg grain/kg N	0.3	28.2	10.6	10.3
AE_P, kg grain/kg P	-5.2	38.9	18.2	20.9
AE_K, kg grain/kg K	1.9	28.5	18.0	20.1
Rajshahi (n = 9)				
AE_N, kg grain/kg N	3.0	20.5	10.6	8.3
AE_P, kg grain/kg P	13.4	61.3	25.4	20.6
AE_K, kg grain/kg K	3.8	16.6	7.4	6.1
Rangpur (n = 4)				
AE_N, kg grain/kg N	12.9	18.2	15.5	15.5
AE_P, kg grain/kg P	9.0	26.7	20.6	23.3
AE_K, kg grain/kg K	0.6	11.2	5.0	4.1

based on indigenous nutrient supply and nutrient requirement for particular yield targets needs to be adopted for sustaining productivity of R-M systems in Bangladesh.

Conclusions

There were variable yield responses of maize to N, P, and K across the three experimental districts in Bangladesh. Likewise, the agronomic efficiencies of N, P, and K also varied across the three sites. Grain yields in N, P, and K omission plots were not well-correlated with native soil N, P, and K contents, respectively. BC-SA

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Evaluation of Nutrient Expert™ for Wheat

By A. Kumar, K. Majumdar, M.L. Jat, M. Pampolino, B.R. Kamboj, D.K. Bishnoi, V. Kumar and A.M. Johnston

On-farm nutrient omission trials in Haryana under contrasting tillage and residue retention treatments showed that wheat yield varied across sites. Site-specific nutrient recommendations from Nutrient Expert, a recently developed wheat nutrient decision support tool, increased wheat yields and farmer profits over existing farmer fertiliser practices and generalised recommendations under both tillage scenarios.

Nutrient Expert (NE) for wheat is a recently developed (2010-11), easy-to-use, computer-based, interactive decision support tool that can rapidly provide nutrient recommendation for wheat grown in a farmer field, either in the presence or absence of soil testing data (Pampolino et al., 2012). This tool has been developed from extensive on-farm research data on wheat grown under variable soil and climatic conditions. Nutrient Expert for wheat estimates attainable yield for a farmer's field based on the growing conditions, determines the nutrient balance in the cropping system based on yield and fertiliser/manure applied to the previous crop and combines this information with expected N, P and K response in the concerned field to generate a site-specific nutrient recommendation for wheat. The major objectives of the present study were to: (1) assess the variability in soil nutrient supplying capacities in Haryana soils under CT and CA practices and (2) evaluate on-farm performance of NE for wheat.

Sixty-four (64) on-farm nutrient omission trials (47 under CA and 17 under CT) were set up in 2009-10 and 2010-11 by IPNI and the International Maize and Wheat Improvement Centre (CIMMYT) under the Cereal Systems Initiative for South Asia (CSISA) project. The trials covered variable wheat growing environments in Karnal, Kurukshetra, Kaithal, Ambala, Yamunanagar, Panipat, and Sonepat districts of Haryana. The study area falls under the northwestern plain agro-climatic zone. The annual precipitation ranges from 400 to 600 mm and soil textures range from sandy loam to silty clay loam. Wheat was planted using CT or CA practices under irrigated ecology. For CT, 2 to 3 harrowing, 1 to 2 cultivations, and 1 to 2 planking operations were done during field preparation and wheat was sown using a zero-till multi-crop planter (Jat et al., 2010). For CA, a Turbo Happy seeder (Sidhu et al., 2007) was used for seeding wheat in full rice residue while the zero-till multi-crop planter was used for partial residue retention (standing stubbles of rice residue). The following four treatments were assessed in the on-farm experiments: Ample NPK; Omission of N with full P and K; Omission of P with full N and K; and Omission of K with full N and P. Ample NPK rates for wheat were 150 to 180 kg N, 90 kg P_2O_5 and 100 kg K_2O per hectare for yield targets between 5 to 6 t/ha. Nutrients were applied in excess of the actual requirement of wheat crop, following the omission plot experiment protocol, to ensure no limitation of nutrients except the omitted one. Deficient secondary and micronutrients were applied to each plot as per the state recommended application rates.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; CT = conventional tillage; CA = no-till or conservation agriculture; FP = farmer (fertiliser) practice; SR = state (fertiliser) recommendation; CRI = crown root initiation; DAS = days after seeding; IPNI = International Plant Nutrition Institute.

An omission plot trial site in Haryana with differential residue retention. Mr. Anil Kumar on (left) and Dr. Pampolino (right).

Nutrient recommendations from the NE were also evaluated against existing nutrient management practices under CT and CA in 40 farmer participatory trials during winter 2010-11 and 2011-12. These NE trials had five treatments including: T_1: NE (80:20) – NE recommendation with N split as 80% basal and 20% at second irrigation (40 to 45 DAS); T_2: NE (33:33:33) – NE recommendation with N split as 33% basal, 33% at CRI stage (20 to 25 DAS) and 33% at second irrigation (40 to 45 DAS); T_3: SR (50:50) with N split as 50% basal and 50% at CRI stage; T_4: FFP; T5: NE 80 GS (GreenSeeker™) variable rate – 80% of the NE N recommendation applied basally and further application of N based on optical sensor-guided prescriptions at Feekes 7/8 based on the calibration curve of Bijay-Singh et al., 2011. The average NPK rates in the NE evaluation trial are given in **Table 1**.

Effect of Tillage on Spatial Variability in Wheat Yield and Nutrient Supplying Capacity

Average wheat yield in the ample NPK plot across all sites

Table 1. NPK rates used in different treatments in the Nutrient Expert evaluation trial.

Tillage Practice	Nutrient Expert (80:20)			Nutrient Expert (33:33:33)			State recommendation			Farmer's practice			Nutrient Expert (80: Greenseeker® variable rate)		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
No-till (CA)	156	53	82	156	53	82	150	60	60	170	58	1	150	51	76
Conventional tillage (CT)	156	53	86	156	53	86	150	60	60	170	58	1	151	53	83

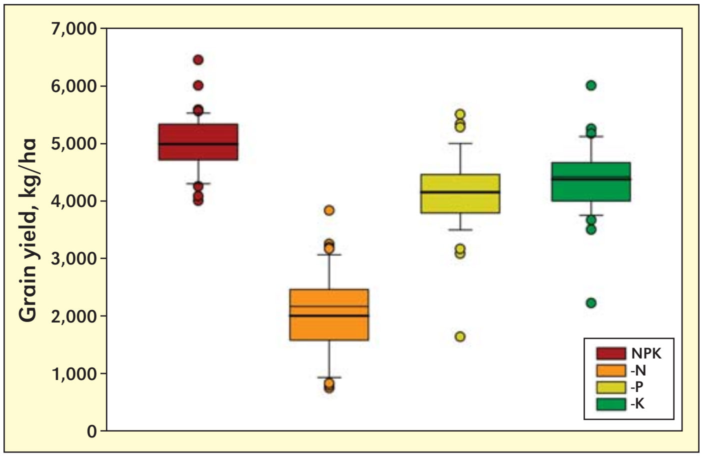

Figure 1. Wheat yield variability under no-till across sites. The error bars represent 10th to 90th percentile of the data, and the thick line represents the mean.

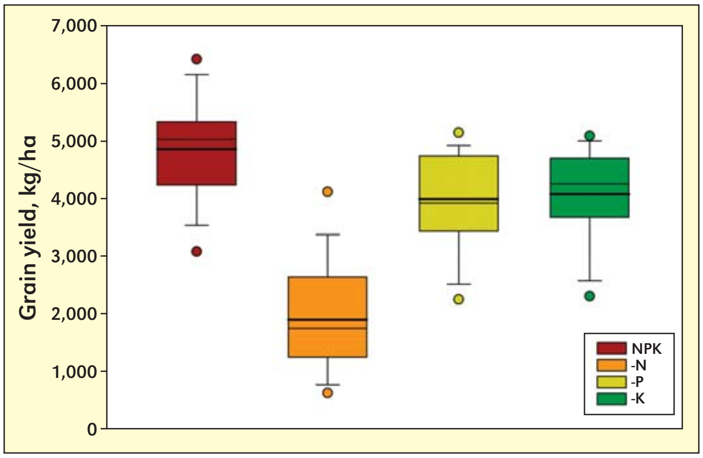

Figure 2. Wheat yield variability under conventional till across sites. The error bars represent 10th to 90th percentile of the data, and the thick line represents the mean.

under CA (n=47) was 4,992 kg/ha (**Figure 1**). Omission of N, P and K from the ample NPK caused variable yield loss, with an average yield loss of 60%, 17% and 13%, respectively. This data confirms that a large spatial variability exists in nutrient supplying capacities among farmer fields across sites due to historical differences in crop and fertiliser management. Average wheat grain yield in CT plots (n=17) was 4,885 kg/ha (**Figure 2**). Average yield losses in the CT wheat due to omissions of N, P and K were similar to no-till wheat. However, yield variability was much higher in CT wheat when compared with CA wheat. This was also evident through higher error estimation in the ample NPK, N omission, P omission, and K omission plot yields in the CT wheat (data not shown). Conventionally-tilled plots received a number (3 to 4 passes) of preparatory tillage operations before planting of wheat. The number of tillage operations, depth of tillage, and extent of residues incorporated during tillage may vary between farmers' fields and may compound the inherent variability due to historical management differences between CT fields. In contrast, spatial variability among farmers' fields under CA is influenced by historical management only.

Nitrogen, P or K responses in the contrasting tillage practices, estimated by subtracting the omission plot yields from

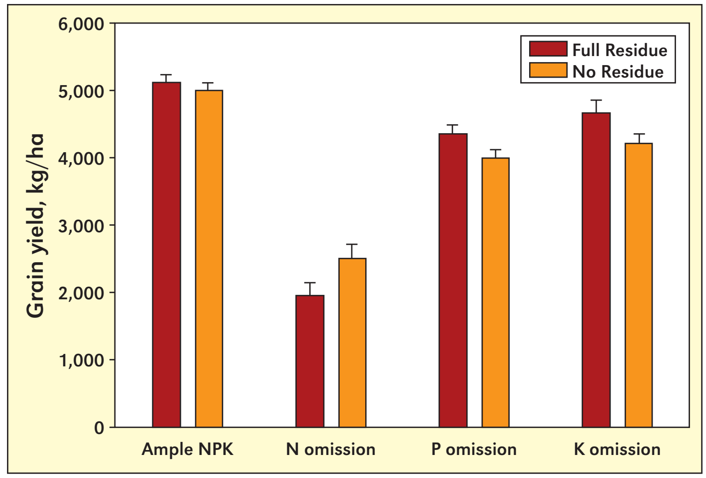

Figure 3. Effect of residue management on wheat grain yield under no-till. The bars represent the standard error.

the ample treatment yield, was not significantly different (data not shown). No-till wheat is planted in Haryana under various residue management scenarios, such as full retention of residues from the previous rice crop, partial retention of rice residue (anchored rice stubbles), and complete removal/burning of residues. The effect of differential residue management within CA on the yield of wheat was estimated (**Figure 3**). A comparison of yield in ample NPK, N omission, P omission, and K omission plots under full residue retention and complete removal of residues showed higher yields when the full residue of the previous rice crop was retained. The N omission plot yield was higher under complete removal of rice residue. Higher availability of nutrients from retained residues in the ample NPK and P or K omission plots probably increased yields, while greater immobilisation of N in the full residue retained plots caused yield decline in the N omission plots.

On-farm Performance of Nutrient Expert for Wheat

Validation of the NE decision support tool in wheat showed that the NE-based recommendation significantly improved wheat yield over FP and SR (**Table 2**). Farmers in intensive production systems of northwest India are using higher rates of N fertilisers with very little or no K. As K plays a key role in several physiological processes including stress tolerance and grain filling (1,000-grain weight) in wheat, imbalanced use of N and P, and omitting K results in poor grain filling

Table 2. Effects of nutrient management and tillage practices on wheat grain yield (kg/ha) [average of two years (2010-11 and 2011-12, n=29)].

	Tillage management systems	
Nutrient management	No-till (CA)	Conventional Till (CT)
Nutrient Expert (80:20)	5,174 b[1] A[2]	4,970 b A
Nutrient Expert (33:33:33)	5,521 a A	5,239 a B
State recommendation	5,093 b A	4,969 b A
Farmer's practice	4,766 c A	4,532 c B

[1]Within column, means followed by the same small letter are not significantly different at p = 0.05 using Tukey's HSD test; [2]Within rows, means followed by the same capital letter are not significantly different at p = 0.05 using Tukey's HSD test.

and lower yields. Application of the NE-recommended N rates in three equal splits performed better than applying 80% of the recommended N rate as a basal application. The NE tool, validated under both CA and CT, effectively captured the biophysical differences between the two tillage practices. The validation trial results also showed that wheat yield in farmers' plots (**Table 2**) across sites were higher under conservation tillage practices.

In another set of farmers' participatory field trials, the NE-based recommendations were supplemented with GreenSeeker™ optical sensor-based N prescriptions at Feekes 7/8 and then compared with SR and FP. The results of these trials (n=11) revealed that wheat yields with NE and NE+GS recommendations were at par but significantly higher than FP under both the scenarios (**Table 3**). No-till practices in wheat are now quite popular, particularly in northern India, and a nutrient management decision support tool that can handle contrasting scenarios of tillage will be more acceptable for use.

Economic assessment of the different fertiliser management options again showed the usefulness of NE-based fertiliser recommendations in improving farmer profits under both the tillage scenarios (**Table 4**). Among the NE-based treatments, N applied in three equal splits at critical wheat growth stages produced maximum profits due to higher yields in this treatment.

Conclusions

Better understanding of indigenous nutrient supplying capacity of soils under varying growing environments (tillage, residue management practices etc.) and utilising this information to guide nutrient management in wheat can improve yields and economics over existing practices. The Nutrient Expert decision tool can be an effective tool for farmers, industry agronomists and government extension personnel to provide field-specific nutrient recommendation to individual wheat farmers for improved yields and farm profits. BC-SA

Table 3. Effect of nutrient management and tillage practices on wheat grain yield (kg/ha) [average of two years (2010-11 and 2011-12, n=11)].

	Tillage management systems	
Nutrient management	No-till (CA)	Conventional till (CT)
Nutrient Expert (80:20)	5,334 b[1] A[2]	5,089 b A
Nutrient Expert (33:33:33)	5,800 a A	5,323 ab B
State recommendation	5,240 b A	5,069 b A
Farmer's practice	4,815 c A	4,551 c A
Nutrient Expert (80: Greenseeker variable rate)	5,530 ab A	5,410 aA

[1]Within column, means followed by the same small letter are not significantly different at p = 0.05 using Tukey's HSD test; [2]Within rows, means followed by the same capital letter are not significantly different at p = 0.05 using Tukey's HSD test.

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Table 4. Economics of different fertiliser management options (n=29).

Treatment	Tillage[1]	Fertiliser (NPK) cost, Rs/ha (A)	Wheat yield, kg/ha (B)	Returns[2], Rs/ha (C)	Returns over fertiliser cost, Rs/ha (D = C-A)	Additional fertiliser cost over FP, Rs/ha (E)	Additional gain in returns over FP, Rs/ha (F)	Per unit gain over FP, (G = F/E)
Nutrient Expert (80:20)	CA	6,226	5,161	62,541	56,315	842	4,129	4.90
Nutrient Expert (33:33:33)	CA	6,226	5,507	66,774	60,548	842	8,361	9.93
State recommendation	CA	6,065	5,079	61,524	55,460	681	3,273	4.81
Farmer's practice	CA	5,384	4,754	57,570	52,187	0	0	0.00
Nutrient Expert (80:20)	CT	6,291	4,955	60,164	53,874	907	4,495	4.96
Nutrient Expert (33:33:33)	CT	6,291	5,223	63,426	57,135	907	7,757	8.55
State recommendation	CT	6,065	4,956	60,139	54,074	681	4,696	6.90
Farmer's practice	CT	5,384	4,519	54,762	49,378	0	0	0.00

[1]CA = conservational agriculture (no-till); CT = conventional tillage; [2]Cost of N = Rs. 22.5/kg (NE), Rs. 22.74/kg (SR), Rs. 21.02 (FFP); P_2O_5 = Rs. 30.66/kg; K_2O = Rs. 13.58/kg; Wheat price = Rs. 12.03/kg. Different N prices for different treatments were used because of the large difference in Urea and DAP prices and the cost of N for each treatment was dependant on how much of Urea or DAP was used in that particular treatment.

Dr. Sudarshan Dutta Appointed IPNI Deputy Director (East), South Asia Program

Dr. Sudarshan Dutta

Dr. Sudarshan Dutta joined the staff of the International Plant Nutrition Institute (IPNI) as of May 1, 2012. Dr. Dutta is based in Kolkata, West Bengal, and will be responsible for the East Zone of the South Asia program—a region that covers the states of Chhattisgarh, Jharkhand, Bihar, West Bengal, Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya, and Sikkim, as well as Bangladesh.

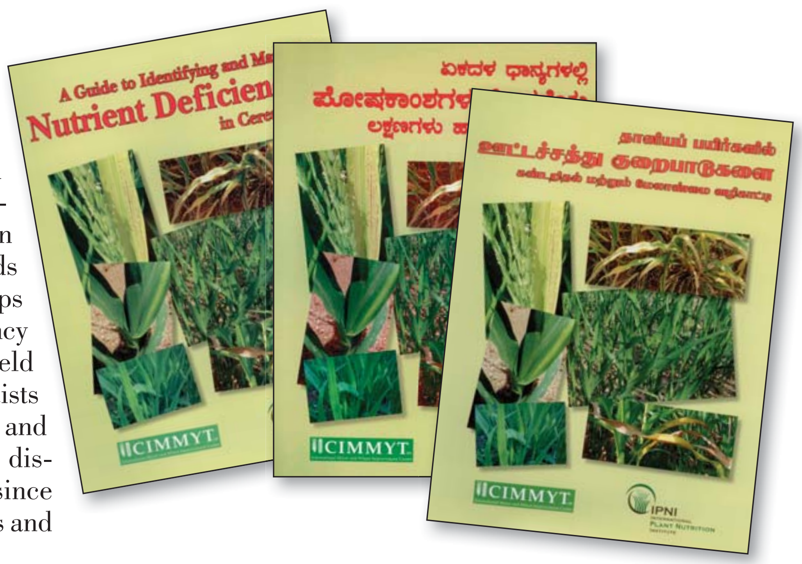
"Dr. Dutta is again a valuable addition to our scientific staff, and IPNI will benefit greatly from his strong training in soil chemistry and environmental assessment," said IPNI President Dr. Terry Roberts. "We welcome Sudarshan to our staff as we are confident he will make an outstanding contribution towards our Program goals for South Asia."

Dr. Dutta received his B.Sc. in Agriculture (Adv. Soil Science) in 2003 from the State Agricultural University (Bidhan Chandra Krishi Viswavidyalaya), in West Bengal. He completed his M.Sc. in 2005 from Punjab Agricultural University, where he examined sorption and desorption behaviors of lead in different soils of India. Dr. Dutta obtained his Ph.D. in 2011 from the University of Delaware. His dissertation title was "Transport of free and conjugated estrogens in runoff from agricultural soils receiving poultry manure: A field and watershed scale evaluation." Since his completion of his Ph.D., Dr. Dutta continued his work at the University of Delaware as a Post Doctoral Research Associate within the Watershed Hydrochemistry group where he has made a significant contribution to the understanding of the fate and transport of nutrients (N and P), trace elements (As, Cu, and Zn), and emerging contaminants including steroidal hormones, antibiotics, and their degraded by-products within different runoff components of agricultural watersheds. Dr. Dutta's research has also involved quantifying exports of dissolved organic matter from the Fair Hill Natural Resource Management Area (NRMA) - a forested watershed in Maryland.

His research has generated a number of peer-reviewed journal articles and guest lecture invitations at the undergraduate and graduate student level. Dr. Dutta's research interests for South Asia include the implementation of regionally appropriate management practices supportive of 4R Nutrient Stewardship, soil conservation, and sustainable agriculture.

A Guide to Identifying and Managing Nutrient Deficiencies in Cereal Crops

IPNI South Asia Program staff, in cooperation with scientists from State Department Agriculture, Government of Rajasthan, and International Maize and Wheat Improvement Center (CIMMYT), developed a field guide for identifying and managing nutrient deficiencies in cereals last year. The guide is designed to describe the appearance and underlying causes of nutrient deficiencies in maize, wheat, sorghum, pearl millet, and barley. Hundreds of excellent deficiency photographs in the field guide helps the user to understand the development of nutrient deficiency symptoms through the growth stages of the crops. The field guide, developed in English, was distributed among scientists and extension workers in India, Bangladesh and Nepal, and has been widely appreciated as a significant knowledge dissemination tool. On popular demand, the guidebook has since been translated in Tamil and Kannada regional languages and translation in Hindi is in progress.



Current Research Supported by IPNI South Asia Programme

At the heart IPNI's regional educational programmes is its support of local research. Below is a listing of the current research being funded throughout the IPNI South Asia Region. More details on these projects, and others conducted in field throughout the world, can be obtained from IPNI Staff or from our on-line research database found at: http://www.ipni.net/research.

Multi-region

Nutrient Expert Validation in Maize and Wheat in Punjab, Haryana, Rajasthan, Uttar Pradesh, Bihar, West Bengal and Jharkhand.

Nutrient Omission Plot Studies in Punjab, Haryana, Rajasthan, Madhya Pradesh, and Maharashtra for Developing Site-Specific Nutrient Management strategies.

North and West India

Addressing Multi-Nutrient Deficiencies through Site-Specific Nutrient Management.

Fertility Mapping and Balanced Fertilization for Sustaining Higher Productivity of Pearl Millet-Wheat Cropping System in Agra District.

Site-Specific Nutrient Management for Rice-Wheat in Punjab.

Site-Specific Nutrient Management for Rice-Wheat in Haryana.

Comparative Evaluation of Nutrient Dynamics under Conventional and No-till Systems of Crop Establishment in Rice-Wheat and Rice-Maize Cropping Systems.

Inventory of Available Potassium Status and Modeling its Relationships with Potassium Content, Yield, and Quality of Sugarcane for Site-Specific Nutrient Management in Maharashtra.

Development of Soil Fertility Map as a Decision Support Tool for Fertilizer Recommendation in Citrus.

East India and Bangladesh

Site-Specific Nutrient Management for Rice-Maize Cropping Systems in Bangladesh.

Assessment of Soil Potassium Supplying Capacity from Soil Nutrient Reserves and Dissemination of Nutrient Management Technologies through Nutrient Manager.

GIS-Based Spatial Variability Mapping of Agricultural Holdings for Precision Nutrient Management in the Red and Lateritic Soil Zone.

Site-specific Nutrient Management for Rice-Maize Systems in Bihar.

Global Maize Project in India: Ranchi, Jharkhand.

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.

South India and Sri Lanka

Improving Nutrient Use Efficiency and Profitability in Rainfed Production Systems.

Maximizing Yield of Groundnut through Improved Nutrient Management Practices in Acid Soils of Orissa.

Site-Specific Nutrient Management in Maize Growing Districts of Tamil Nadu.

Global Maize Project in Dharwad, Karnataka, India on Site-Specific Nutrient Management in Maize-Wheat Cropping System in Northern Karnataka.

Nutrient Expert Validation in Maize and Wheat in Andhra Pradesh, Tamil Nadu, Karnataka, and Orissa.

Nutrient Omission Plot Studies in Andhra Pradesh, Tamil Nadu, Karnataka, and Orissa for Developing Site-Specific Nutrient Management Strategies.

IPNI South Asia Programme regions are staffed by Dr. Kaushik Majumdar, Director, South Asia with regional responsibility in North and West India, Dr. Sudarshan Dutta, Deputy Director (East India & Bangladesh), and Dr. T. Satyanarayana, Deputy Director (South India & Sri Lanka). BC-SA

Balanced Fertilization – the Key to Food Security

One of the cornerstones of IPNI programs around the world is demonstrating the role of balanced nutrient management in crop production. Our history in South Asia is no different, with a long list of scientific articles, extension publications, videos, and illustrative posters developed over the past 23 years. While this approach may sound rather simple, the current food security challenges in South Asia are crying out for just that—demonstration of the impact of balanced nutrient management.

Recent research results in India clearly demonstrate that a future heavily based on N and P use is wrought with challenge. IPNI has recently summarised a number of research projects across the country to show that insufficient K, secondary, and micronutrients are holding back productivity. The yield results are clear, and the economic benefits to correcting these imbalances are also clearly in favour of the Indian farmer.

Moving from research results to practical tools in the field must continue to be our focus for moving forward. Research results provide us with the confidence to take the necessary steps in advancing the practice of agronomic, economic, and environmentally sustainable nutrient management. The challenge so often remains this actual move, or as we in IPNI often call it the "translation" of research results into action in a farmer's field. We at IPNI are very excited about the recent progress we have made in the adaptation of decision support tools like Nutrient Expert® for maize and wheat in India. These tools have the potential to put into the hands of farmer advisors a site-specific nutrient recommendation program that has proven to address the issues related to unbalanced nutrient management.

Did you know that 1 + 1 + 1 can sometimes = 10! Over the last several years our programs in IPNI have placed a major emphasis on collaboration with past and new partners. These collaborative efforts in research and development have resulted in an empowering growth of our own staff, as well as many of our partners. Most of us are focused on the same ultimate objective…achieving a process that will guide South Asia forward in meeting future food security challenges. If our current activities are any example of the potential for collaboration, the future looks very positive.

At IPNI we are moving forward…sticking to the basics of balanced nutrition, supporting it with sound research results, developing an appropriate delivery mechanism to engage the largest number of stakeholders and doing all this in a collaborative environment.

Adrian Johnston
IPNI Vice President, Asia and Africa Group Coordinator

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