BETTER CROPS
SOUTH ASIA

A Publication of the International Plant Nutrition Institute (IPNI)   Volume 8, Number 1, 2014

Focus Issue on Nutrient Expert® - A Decision Support Tool for Site-Specific Nutrient Management

In This Issue...

Developing and Evaluation of Nutrient Expert®

Adapting Recommendations to Socio-economics

Going Global with Improved Fertiliser Recommendations

Also:

2014 IPNI Scholar Award Recipients

...and much more

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BETTER CROPS–SOUTH ASIA

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Our cover: IPNI South Asia Staff working together with farmers on implementing their own fertiliser recommendations based on Nutrient Expert®.

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CONTENTS

Welcome...

You are reading the eighth issue of *Better Crops South Asia*. This publication is released annually in the fourth quarter and follows a format similar to our quarterly publication known as *Better Crops with Plant Food*.

For 2014, the issue is focused on the Nutrient Expert® Decision Support Tool. The need to develop a science-based fertiliser recommendation tool in South Asia has been the focus of IPNI for several years. While soil testing has been the standard approach to past recommendations, the cost, access or timeliness for delivery of results have limited its use significantly. The development of Nutrient Expert® (NE) as a decision support tool advisors can use to make site-specific nutrient management recommendations for small-holder farmers is our response to this challenge. With the data from on-farm verification trials, and the support of many in the scientific community, we are encouraged to advance the use of NE as one of the options that supports science-based fertiliser recommendations.

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

Dr. Terry L. Roberts, President, IPNI

IPNI Scholar Award Recipients Announced for 2014

The IPNI Scholar Award Program has once again expanded its reach by awarding Scholarships to 30 graduate students in 2014. Each Scholar receives a certificate, the equivalent of US$2,000, and they are welcomed as the latest additions to a prestigious group of young scientists who have demonstrated great dedication and promise within their respective careers.

"We have had another record response to our Scholar Award program this year," said Dr. Terry L. Roberts, IPNI President. "The global representation of universities and the wide array of fields of study that were represented in this year's submissions were impressive. The academic institutions these young people represent, and their professors and advisers, can be proud of their student's accomplishments. Our selection committee adheres to rigorous guidelines in considering important aspects of each applicant's academic and personal achievements."

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

Dheeraj Kumar Tiwari

Mr. Dheeraj Kumar Tiwari, C.C.S. Haryana Agricultural University, India, is pursuing his Ph.D. in agronomy since 2013. His dissertation is titled "Performance of maize hybrids under different planting methods and nitrogen levels." The focus of his research is on evaluating the effect of N levels on growth and yield of maize hybrids under different planting methods and N levels on economics, quality and physicochemical properties of soil. In the future, Mr. Tiwari wants to become a research scientist in an international organization.

Ramesh Chandra Yadav

Mr. Ramesh Chandra Yadav, Indian Agricultural Research Institute, India, is working toward his Ph.D. in soil science. The focus of his research is on the development and testing of nano-based novel carriers of N for enhancing its use efficiency and reducing greenhouse gas emissions under elevated carbon dioxide and temperatures. It is expected that this study will lead to the development of nano-clay composites that can then be used as slow-release N fertilisers to improve N use efficiency and mitigate the effect of climate change on crop productivity. Mr. Yadav aims to establish a career in agricultural research and contribute to the well being of the farming community.

Krishnendu Ray

Mr. Krishnendu Ray, Bidhan Chandra Krishi Viswavidyalaya, India, is completing requirements for his Ph.D. in agronomy. His dissertation title is "Site-specific nutrient management for improving nutrient use efficiency in hybrid *rabi* maize cultivars in the lower Gangetic plains." This study will evaluate the impact of site-specific nutrient management on growth, yield and quality of maize by managing large spatial and temporal variability observed in smallholder farming systems. In the future, Mr. Ray wishes to extend his research further and quantify soil-plant-atmosphere interactions for better crop and soil management.

J.A.S. Chathurika

Ms. Jayathunga Arachchige Surani Chathurika, Postgraduate Institute of Agriculture, Sri Lanka, is working toward a Ph.D. in soil science. Her dissertation is titled "Improving soil fertility of low productive lands by beneficial management practices for maize." The main objective of her study is to identify beneficial management practices to improve soil fertility of marginal agricultural lands. This research will help to develop approaches to improve C sequestration using available resources, thereby improving the overall soil fertility to support higher crop yields on marginal agricultural lands in the long-run. For the future, Ms. Chathurika wishes to pursue a career in soil science research and extension.

Development and Evaluation of Nutrient Expert® Decision Support Tool for Cereal Crops

By Mirasol F. Pampolino, Christian Witt, Julie Mae Pasuquin, Adrian M. Johnston, and Myles J. Fisher

Nutrient Expert® (NE) is a computer-based decision support tool that uses the principles of site-specific nutrient management for developing fertiliser recommendations tailored to a specific field or growing environment. Results of field evaluation have shown that NE is effective in providing recommendations that can increase yields and profits compared with farmers' current practices. NE accounts for the important factors affecting site-specific recommendations, which makes it an excellent tool for providing tactical information to crop advisors and farmers as well as strategic information to high-level decision makers. NE is also a suitable starting point for developing nutrient management tools to reach more users.

The demand for increased cereal production to feed an increasing world population will not be met just by the expansion in cultivated area, but more by intensifying production of wheat, rice and maize. Currently, cereal yields are only 40 to 65% of their potential, mostly because nutrient management does not consider crop's dynamic response to the environment. Intensification will therefore need nutrient management that produces high yields, while preserving soil quality and protecting the environment.

Site-specific nutrient management (SSNM) is a set of nutrient management principles, which aims to supply a crop's nutrient requirements tailored to a specific field or growing environment. Although SSNM has been proven to increase yields and productivity in on-farm trials, there has been little acceptance. The reason being many extension agents still perceive SSNM as complex, requiring an understanding of concepts and methods outside their experience. A simple nutrient decision support tool based on the principles and guidelines of SSNM, such as Nutrient Expert® (NE), will help crop advisors develop strategies to manage fertiliser N, P and K tailored to a farmer's field or growing environment. As a computer-based decision support tool, NE combines all the steps and guidelines in SSNM into a simple software tool tailored for crop advisors, especially the not-so-technical users such as the extension agents in developing countries.

The conceptual framework used in the development of NE is applicable to any cereal crop and geographic location. The algorithm for calculating fertiliser requirements in NE is determined from a set of on-farm trial data using SSNM guidelines. In SSNM, the N, P and K requirements are based on the relationships between balanced uptake of nutrients at harvest and grain yield (Buresh et al., 2010; Setiyono et al., 2010). This

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

Dr. Mirasol Pampolino (far right) **visiting the Nutrient Expert® validation trials** at the CSISA hub site in Bheemarayanagudi, Karnataka with Dr. Kaushik Majumdar (second from right) and Dr. T. Satyanarayana (far left) and staff from CIMMYT, and UAS Raichur.

relationship is called the internal nutrient efficiency and is predicted using the quantitative evaluation of the fertility of tropical soils (QUEFTS) model (Janssen et al., 1990). The fertiliser requirement for a field or location is estimated from the expected yield response to each fertiliser nutrient, which is the difference between the attainable yield and the nutrient-limited yield. These parameters are determined from nutrient omission trials in farmers' fields, while attainable yield is the yield for a typical year at a location using best management practices without nutrient limitation. Nutrient-limited yield is that when only the nutrient of interest is omitted. The amount of nutrients taken up by a crop is directly related to its yield so that the attainable yield indicates the total nutrient requirement and the nutrient-limited yield indicates the indigenous nutrient supply (Dobermann et al., 2003). The yield response indicates the nutrient deficit, which must be supplied by fertilisers. Nutrient Expert® follows SSNM guidelines for fertiliser application and split dressings, which consider the crop's nutrient demand at critical growth stages (Witt et al., 2009; IRRI, 2011).

Table 1. Characteristics of the sites for the field evaluation of Nutrient Expert® for Hybrid Maize in Indonesia and the Philippines, 2010-2011.

Country & Site No.	Province	District/Municipality	Ecosystem†	Cropping pattern	Farmers
Indonesia					
1	East Java	Kediri	IR	Rice-rice-maize	5
2	Lampung	Punggur	RF	Maize-maize	5
3	North Sumatra	Langkat	RF	Maize-maize	5
4	North Sumatra	Langkat	IR	Rice-rice-maize	4
5	South Sulawesi	Bone	RF	Maize-maize	3
Philippines					
1	Pangasinan	Bayambang	RFSI	Rice-maize	5
2	Laguna	Calamba	RF	Maize-maize	3
3	Occidental Mindoro	Abra de Ilog	RFSI	Rice-maize	4
4	Iloilo	Cabatuan	RF	Maize-maize	6
5	Negros Occidental	Murcia	RF	Maize-maize	7
6	Davao	Tugbok	RF	Maize-maize	2
7	Maguindanao	Datu Odin Sinsuat, Sultan Mastura, Ampatuan, Sultan Kudarat	RF	Maize-maize	4

† IR = irrigated, RF = fully rainfed, RFSI = rainfed with supplemental irrigation.

Table 2. Agronomic and economic performance of Nutrient Expert® for Hybrid Maize at five sites (3 to 5 farmers per site) in Indonesia and seven sites (2 to 7 farmers per site) in the Philippines, 2010–2011.

	-------- Indonesia (n = 22) --------				-------- Philippines (n = 31) --------			
Parameter	FFP	NE	(NE – FFP)†		FFP	NE	(NE – FFP)†	
Grain yield, t/ha	7.5	8.4	+0.9	***	7.5	9.1	+1.6	***
Fertiliser N, kg/ha	173	160	-12	ns	107	132	+25	**
Fertiliser P, kg/ha	19	14	-4	*	12	15	+4	**
Fertiliser K, kg/ha	23	34	+11	**	18	29	+11	**
Fertiliser cost, US$/ha	126	126	0	ns	176	240	+64	***
GRF‡, US$/ha	1,761	2,032	+271	***	1,738	2,117	+379	***

***, **, *: significant at 0.001, 0.01 and 0.05 level respectively; ns = not significant
† Statistical analysis was performed with JMP version 8 (SAS Institute, 2009) using Mixed Procedure with sites as random effects.
‡GRF refers to the gross return above seed and fertiliser costs; estimated using actual local prices of seed, fertiliser and maize grain at US$1 = IDR 8,850 (Indonesia), Php 43 (Philippines).

Nutrient Expert® estimates the attainable yield and yield response to fertiliser from site information using decision rules developed from on-farm trials. It uses:

(a) Characteristics of the growing environment like water availability (irrigated, fully rainfed, rainfed with supplemental irrigation) and any occurrence of yield-limiting constraints such as flooding, drought etc.;
(b) Soil fertility indicators like soil texture, soil color and organic matter content, soil test for P or K (if any), historical use of organic materials (if any), problem soils (if any);
(c) Crop sequence in the farmer's cropping pattern;
(d) Crop residue management and fertiliser inputs; and
(e) Farmers' current yields.

The development of NE is done through collaboration with crop advisors from both public and private sectors, as well as with scientists and extension specialists to ensure that NE meets users' needs and preferences, thereby increasing the likelihood of its adoption. Collaboration is carried out through a series of dialogues, consultations and partnerships towards (a) collection of locally-available agronomic data and information, (b) integration of local user's preferences such as use of local language, measurement units, locally-available fertiliser sources, etc. and (c) field testing, evaluation and refinement of the NE software.

Nutrient Expert® for Hybrid Maize

As NE can be applied to any cereal crop, the NE for Hybrid Maize (NEHM) was developed for favorable, tropical rainfed and irrigated environments. It was designed to ask simple questions, which can be answered from existing information for a field or recommendation domain. The questions were grouped into five modules, viz., (1) current practice, (2) planting density, (3) SSNM rates, (4) sources and splitting and (5) profit analysis. The first three modules include questions that determine attainable yield and yield responses to fertiliser. The SSNM rates module provides N, P and K requirements for the selected attainable yield.

Consistent with SSNM, which promotes the 4Rs of nutrient stewardship (right source, right rate, right time and right place), NEHM specifies the amount and timing of fertiliser to apply, including split applications. In the sources and splitting module, NEHM recommends two or three splits for N, that all P be applied at or soon after sowing and that K be applied once or twice depending on the rate. It selects among fertilisers that the user specifies, choosing those whose nutrient contents match the requirement for optimal split dressings. It also recommends optimum plant population specifying both plant and row spacing. The sources and splitting guidelines are location-specific with each recommendation.

The SSNM strategies for maize in Southeast Asia (Witt et al., 2009) comprised the algorithm for calculating fertiliser N, P and K requirements in NEHM. These SSNM strategies are based on known attainable yield and yield responses and were developed using 2004 to 2008 data from on-farm trials with hybrid maize at 19 important sites in Indonesia, Philippines and Vietnam. It provided a range of attainable yields and yield responses to fertiliser N, P and K across diverse environments characterised by variations in amount and distribution of rainfall, varieties and crop durations, soils and cropping systems.

The NEHM model developed was validated in Indonesia and the Philippines in sites without nutrient omission trial data. Existing site and farming information were used to estimate attainable yield and expected yield responses to fertiliser and generate fertiliser recommendation for each field or location. Some users developed fertiliser guidelines for a field, using an individual farmer's data, while others used it for a recommendation domain using data from several representative farmers. The domain-level recommendations were used to develop quick guides for maize for larger geographic areas such as municipalities or districts.

The NEHM recommendations were tested in farmers' fields (plot size $\geq$ 0.1 ha) against farmer's fertiliser practice (FFP) in 2010–2011 at five sites in Indonesia (3 to 5 farmers per site) and seven sites in the Philippines (2 to 7 farmers per site) (**Table 1**). The sites included key maize production areas with maize-maize or rice-maize cropping sequence under favorable rainfed as well as irrigated environments in the two countries.

NEHM increased yield and profit of farmers in both Indonesia and the Philippines (**Table 2**). Results from 22 farmers' fields across five sites in Indonesia showed that NEHM increased yield by 0.9 t/ha, which increased the gross return over seed and fertiliser costs (GRF) by US$270/ha over FFP. Compared with FFP, NEHM recommendations reduced fertiliser P (–4 kg/ha), increased fertiliser K (+11 kg/ha) and did not significantly change fertiliser N. In the Philippines (with data from 31 fields across seven sites), NEHM increased yield by 1.6 t/ha and GRF by US$380/ha compared with FFP (**Table 2**). Compared with FFP, NEHM gave higher rates of all three nutrients (+25 kg N/ha, +4 kg P/ha and +11 kg K/ha), which substantially increased fertiliser costs (US$64/ha), but still increased profit by about six times the additional investment in fertiliser.

NEHM increased yield and economic benefits of farmers in Indonesia and the Philippines by providing a nutrient management strategy tailored to field-specific or domain-specific conditions. NEHM recommendations ensured that sufficient amount of all nutrients (N, P, K, as well as secondary and micronutrients when deficient) needed to attain the yield goal were applied at the critical growth stages of the maize crop. In Indonesia, farmers' nutrient application rates were not always less than NEHM (**Table 2**), indicating that the yield increase with NEHM could have been due to the balanced application of nutrients, as well as optimising the N splitting ratio and application timing, thus improving the efficiency of applied fertiliser nutrients. In the Philippines, the increase in yield with NEHM was largely due to the increased rates of nutrients applied at critical growth stages as compared to the farmers' nutrient rates and timing of application.

Summary

Results of the field evaluation of NEHM in Indonesia and the Philippines demonstrated the ability of NE to increase farmer's yield and income across a range of climates, soil types and cropping systems. Nutrient Expert® provides crop advisors with a simpler and faster way to use SSNM and it enables strategic formulation of nutrient management guidelines for maize and other crops in different geographic regions and countries. Nutrient Expert® allows the determination of a range of yield goals taking into account the potential yield for the specific area, the attainable yield with optimal nutrient management as well as the farmer's objectives (food security or income) and resources. This provides added value in moving from what are now blanket recommendations to developing nutrient management recommendations that match the goals of the farmer and conditions in specific sites.

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Nutrient Expert®–Maize: A Tool for Increasing Crop Yields and Farm Profit

By T. Satyanarayana, Kaushik Majumdar, Sudarshan Dutta, M.L. Jat, S.K. Pattanayak, D.P. Biradar, Y.R. Aladakatti, Mirasol Pampolino, and Adrian Johnston

Nutrient Expert®-based fertiliser recommendations were validated and demonstrated across 191 major maize growing locations in southern India and Odisha showed an overall increase in yield by 1.1 t/ha over the current farmer fertiliser practice. It also helped in improving the profitability of maize farmers in the region. Nutrient Expert®, which follows the principles of the 4R Nutrient Stewardship approach, proved to be a boon to smallholder farmers in the region.

Comparative performance of Farmer Practice (left farmer), Nutrient Expert® (right farmer) and State Recommendation (Dr. Pattanayak standing near the SR treatment).

Nutrient Expert® (NE), a nutrient decision support tool, is developed by the International Plant Nutrition Institute (IPNI) following the principles of 4R Nutrient Stewardship and site-specific nutrient management (SSNM). NE is an easy-to-use, interactive computer-based decision support tool that can rapidly provide nutrient recommendation for an individual farmers' field in the presence or absence of soil testing data (Pampolino et al., 2012). It was developed in 2010-11 in collaboration with stakeholders including scientists, extension agents, and crop advisors from both government and private organisations. The NE provides crop advisors with a simple and rapid tool to apply SSNM principles in individual farmer's fields through the use of existing site information. Besides providing location specific nutrient recommendations, the tool has options to tailor recommendations based on those resources available to the farmers.

Nutrient Expert® for hybrid maize, a MS Access-based computer application consists of five working modules. Current Nutrient Management Practice, the first module in the software documents the history of maize yields obtained in the farmers' fields and records the corresponding extent of nutrients applied by the farmers both through organic and inorganic fertiliser sources. The Planting Density module decides whether or not the farmer is practicing an optimum plant population in his/her maize field and suggests a suitable plant population in the case of farmer's not practicing an optimum planting density. SSNM Rates, the third and the most critical module of the software, initially establishes an attainable yield target considering the growing environment of the farmer's field. It estimates the indigenous nutrient supplying capacity (contribution from crop residue recycling, addition of organic manures, residual benefit from the previous crop) of the farmer's field, determines yield responses to application of major NPK nutrients and finally arrives at the most appropriate nutrient recommendation adequate for obtaining the targeted attainable yield. The Sources and Splitting module transforms the nutrient rates into fertiliser sources available at farmer's door step and provides a final 4R compliant (i.e., Right Source, Right Rate, Right Time and Right Place) recommendation report to the farmer. The Profit Analysis module compares the cost economics associated with both the SSNM and the farmers' practice and suggests whether or not it is profitable of practicing NE-based fertiliser recommendation.

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

The development and validation of NE during 2010-12, including the accumulation of promising on-farm results, led to the official launching of the NE for free public use on 20 June 2013. This paper summarises the results obtained from the on-farm validation experiments conducted in the southern region of IPNI South Asia Program and compares the performance of NE-based fertiliser recommendations over the other existing nutrient management practices. On-farm experiments evaluating the performance of NE over SR (official fertiliser recommendations by respective states) and FP (farmers' fertiliser application practice) were conducted at 191 major maize-growing sites across Andhra Pradesh, Karnataka, Tamil Nadu, and Odisha. The comparative experiments were distributed in both the *kharif* and *rabi* seasons, and were conducted in varying maize-growing environments, under rainfed and assured irrigated conditions. The study area covered Krishna, Godavari, Guntur and Prakasam districts of Andhra Pradesh; Warangal, Karimnagar, Ranga Reddy and Medak districts of Telangana; Dharwad, Raichur, Bellary, Gulbarga, Yadgir and Bangalore districts of Karnataka; Perambalur, Dindigul, Than-

Table 1. Comparison of Nutrient Expert® (NE) estimated yield responses and the actual on-farm responses.

	NE-estimated response, kg/ha						Actual on-farm response, kg/ha					
	N		P_2O_5		K_2O		N		P_2O_5		K_2O	
Region	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %	Mean	CV, %
Andhra Pradesh	5,573	26	1,287	55	260	45	4,351	36	2,730	60	2,023	63
Karnataka	4,026	23	1,026	58	1,013	31	4,900	17	1,913	47	900	49
Tamil Nadu	3,500	16	625	120	500	115	2,433	48	492	96	447	51
Odisha	3,484	25	1,081	36	532	48	3,125	20	2,210	70	1,135	22

javur, and Coimbatore districts of Tamil Nadu; Nabarangapur, Kalahandi, Sambalpur, Puri and Cuttack districts of Odisha during the kharif and rabi seasons of 2011-13. The experiments were carried out by IPNI in collaboration with the International Maize and Wheat Improvement Centre (CIMMYT), the Directorate of Maize Research (DMR), state agricultural universities (ANGRAU, Hyderabad; UAS Dharwad; UAS Raichur; TNAU Coimbatore; and OUAT Bhubaneswar), fertiliser industry, and farmers. The information on current nutrient management by farmers was collected through a questionnaire by all the stakeholder groups and NE-based fertiliser recommendations were tested against fertiliser recommendations followed in SR and FP. NE was evaluated in terms of NE- estimated attainable yield versus actual maize yields, NE-estimated crop responses versus actual crop responses determined through omission plot technique, and performance of NE over SR and FP was evaluated in terms of fertiliser use, maize grain yield, fertiliser cost, and gross returns above fertiliser cost (GRF).

Comparison of NE-estimated Attainable Yield and Actual Maize Yield

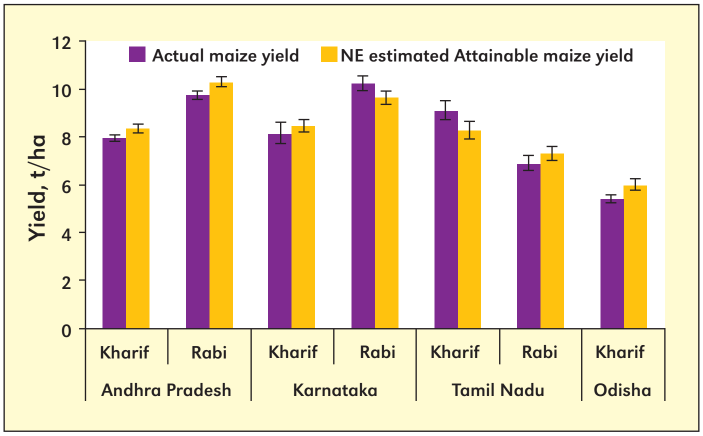

Figure 1. Comparison of Nutrient Expert® (NE)-estimated attainable maize yield versus actual maize yield.

NE is capable of estimating the major nutrient requirement for a practical and challenging yield target established by the software under the SSNM Rates module. The comparative figure (**Figure 1**) showing the NE-estimated attainable yields and the actual maize yields recorded in the farmer fields indicated that NE-based fertiliser recommendations proved to be successful in reaching the yield targets estimated by the software. The NE-estimated average attainable yield targets during the kharif season were 8.3, 8.4, 8.3, and 6.0 t/ha in the respective states of Andhra Pradesh, Karnataka, Tamil Nadu and Odisha. The corresponding average actual maize yields realised in these states were 7.9, 8.2, 9.1. and 5.4 t/ha indicating that fertiliser recommendations developed using NE successfully helped in meeting the targeted attainable yields. The actual maize yields recorded in farmer fields were higher than the NE-estimated attainable yields during the

Table 2. Comparison of nutrient use (kg/ha) between the Nutrient Expert® (NE)-based fertiliser recommendation and Farmer's Practice (FP).

	Kharif (monsoon season)				Rabi (winter season)			
Parameter	NE	FP	NE-FP		NE	FP	NE-FP	
ANDHRA PRADESH		(n = 44)				(n = 51)		
Fertiliser N	110-190 (169)	136-550 (196)	-42	***	150-257 (211)	121-534 (254)	-43	*
Fertiliser P_2O_5	17-84 (61)	25-230 (123)	-62	**	27-92 (55)	21-79 (48)	7	***
Fertiliser K_2O	18-143 (87)	38-150 (80)	7	ns	25-105 (70)	0-168 (64)	6	ns
KARNATAKA		(n = 27)				(n = 11)		
Fertiliser N	106-185 (152)	80-191 (135)	17	ns	110-190 (154)	80-218 (130)	24	ns
Fertiliser P_2O_5	20-81 (46)	46-138 (85)	-39	***	17-64 (42)	58-115 (77)	-35	***
Fertiliser K_2O	22-104 (66)	0-110 (59)	7	ns	29-81 (57)	0-75 (29)	28	*
TAMIL NADU		(n = 12)				(n = 12)		
Fertiliser N	130-210 (182)	147-332 (225)	-43	*	130-150 (148)	95-360 (210)	-62	*
Fertiliser P_2O_5	27-47 (42)	48-79 (67)	-25	***	28-47 (39)	25-258 (111)	-72	*
Fertiliser K_2O	29-55 (43)	48-352 (201)	-158	***	22-59 (31)	50-270 (128)	-97	**
ODISHA		(n = 34)						
Fertiliser N	110-170 (141)	27-367 (103)	38	***	-	-	-	-
Fertiliser P_2O_5	18-67 (41)	20-115 (52)	-11	ns	-	-	-	-
Fertiliser K_2O	21-104 (46)	0-192 (59)	-13	ns	-	-	-	-

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

Table 3. Performance of Nutrient Expert® (NE)-based recommendations for yield and economics of maize in southern region.

		Kharif (monsoon season)							Rabi (winter season)						
Parameter	Unit	NE	FP	SR	NE-FP		NE-SR		NE	FP	SR	NE-FP		NE-SR	
ANDHRA PRADESH (n = 95)		(n = 44)							(n = 51)						
Grain Yield	kg/ha	7,943	6,525	7,297	1,418	***	646	ns	9,736	8,689	8,813	1,047	***	923	***
Fertiliser Cost	₹/ha	5,398	5,996	4,991	-598	ns	407	***	5,515	7,740	5,220	-2,225	***	295	ns
GRF	₹/ha	74,032	59,254	67,979	14,778	***	6,053	***	91,845	79,150	82,910	12,695	***	8,935	***
KARNATAKA (n = 38)		(n = 27)							(n =11)						
Grain Yield	kg/ha	8,153	7,591	7,033	562	ns	1,120	**	10,214	8,831	9,835	1,383	***	379	**
Fertiliser Cost	₹/ha	4,455	5,385	5,543	-930	**	-1,088	**	4,943	4,481	5,543	462	ns	-600	***
GRF	₹/ha	77,075	70,525	64,787	6,550		12,288		97,197	83,829	92,807	13,368		4,390	
TAMIL NADU (n = 24)		(n = 12)							(n = 12)						
Grain Yield	kg/ha	8,774	8,154	7,622	620	**	1,152	ns	7,405	6,550	7,114	855	***	291	ns
Fertiliser Cost	₹/ha	4,232	8,488	4,514	-4,256	***	-282	***	3,546	8,395	5,960	-4,849	**	-2,414	***
GRF	₹/ha	83,230	73,058	71,988	10,172	***	11,242	ns	68,099	57,106	67,595	10,993	***	504	ns
ODISHA (n = 34)		(n = 34)							-						
Grain Yield	kg/ha	5,394	3,611	4,334	1,783	***	1,060	***	-	-	-	-	-	-	-
Fertiliser Cost	₹/ha	3,445	4,264	2,638	819	ns	807	***	-	-	-	-	-	-	-
GRF	₹/ha	50,495	31,846	40,702	18,649	***	9,793	***	-	-	-	-	-	-	-

***, ** and * significant at $p < 0.001$, 0.01 and 0.05 levels; ns = non-significant. GRF = gross return above fertiliser cost.

kharif season in Tamil Nadu. Similar observations were also noticed during the rabi season in Karnataka. NE estimates the attainable yield targets based on robust scientific principles, considers growing environment according to site characteristics and farmers' actual yield while estimating the realistic attainable yield.

Comparison of NE-estimated Yield Responses versus Actual Yield Responses

Yield response to fertiliser application is a function of indigenous nutrient supplying capacity of soil and is determined from soil characteristics (i.e., texture, colour and content of organic matter), historical use of organic inputs (if any), and apparent nutrient balance (for P and K) from the previous crop. The algorithms involved in NE are so rigorous that it captures the required information through logical questions and estimates the yield responses close to the actual yield responses determined through omission plot techniques. The NE-estimated yield responses compared with that of actual yield responses (**Table 1**) showed that N responses estimated with NE were higher by 28, 44 and 11% in Andhra Pradesh, Tamil Nadu and Odisha and lesser by 18% in Karnataka than the actual N response. The NE-estimated P response was higher than the actual P response in Tamil Nadu by 27% and NE-estimated K response was higher than the actual K response in Karnataka and Tamil Nadu by 13 and 12%. In the rest of the regions, NE estimated lower P and K responses than the actual response. Averaged over four states, NE estimated 16% higher N response, 31% lower P_2O_5 response and 29% lower K_2O response over the actual responses observed through omission plot techniques (**Table 1**). The variation in yield response estimated with NE over the actual yield response observed from limited number of omission plot experiments indicated that NE is capable of capturing the temporal variability of nutrient requirement across the seasons along with considering the spatial variability between farmers' fields. Also, NE estimates yield responses based on sound scientific principles even in the absence of soil testing and forms the basis for generating fertiliser recommendations.

Comparison of NE-based Nutrient Recommendation with Farmer Practice

A comparative study of nutrient use between the two nutrient management options (NE and FP) was shown in **Table 2**. During kharif, NE-recommended nutrient use averaged over four states indicated that N, P_2O_5 and K_2O use with NE varied from 106 to 210, 17 to 84, and 18 to 143 kg/ha, with an average of 161, 48, and 61 kg/ha, respectively. The corresponding nutrient use based on FP varied from 136 to 550, 20 to 230, and 0 to 352 kg/ha, with an average of 169, 82, and 100 kg/ha for N, P_2O_5 and K_2O, respectively. On average, the NE-based fertiliser recommendation reduced N, P_2O_5 and K_2O use by 8, 34 and 39 kg/ha indicating 5, 40 and 39% reductions in nutrient use over FP. With the use of NE-based fertiliser recommendation, the lowest N use in FP has increased from 27 to 110 kg/ha in NE, whereas, the maximum N use in FP has decreased from 550 to 210 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 adjustments (increase or decrease) in fertiliser application. Similar observations were also noted for optimising P_2O_5 and K_2O use with NE-based fertiliser recommendations (**Table 2**). The difference between NE and FP for N and P_2O_5 use in Andhra Pradesh, P_2O_5 use in Karnataka, NPK use in Tamil Nadu and N use in Odisha were statistically significant.

The fertiliser application based on NE recommendation during rabi revealed that application of N, P_2O_5 and K_2O across three southern states varied from 110 to 257, 17 to 92, and 22 to 105 kg/ha with an average of 171, 45, and 53 kg/

Odisha farmers expressed satisfaction after visiting the Nutrient Expert® plot.

ha, respectively (**Table 2**). Across all sites, on average, NE reduced N, P_2O_5 and K_2O rates by 27, 33, and 21 kg/ha over FP, resulting in a rate reduction of 14, 40, and 20% of N, P_2O_5 and K_2O use, respectively. NE recommended slightly higher N rates and slightly lower P_2O_5 and K_2O rates during rabi in comparison to the kharif. Nutrient rates generated through NE are based on the estimated yield response to NPK application and NE estimated relatively high N response in rabi season over the kharif season (data not shown). The mean yield response to application of N, P_2O_5 and K_2O during kharif were 3.9, 1.1 and 1 t/ha; whereas, the estimated responses during rabi were 5.2, 0.9 and 1 t/ha, respectively.

NE Use and Improved Yield and Economics of Maize

Data showing the relative performance of NE use over SR and FP for grain yield of maize, fertiliser cost and GRF are given in **Table 3**. Across all sites (n = 117) during the kharif season, NE-based fertiliser use resulted in increased maize yield and economic benefit (i.e., gross return above fertiliser cost or GRF) over FP and SR. Compared to FP, on average it increased yield by 1.1 t/ha and GRF by ₹12,537/ha with a reduction in fertiliser cost (significant only at Karnataka and Tamil Nadu) of ₹1,241/ha. NE-based fertiliser recommendations also increased yield (by 0.9 t/ha) and GRF (by ₹9,844/ha) over SR with a minimal reduction in fertiliser cost (₹-156/ha). NE-based fertiliser recommendations were also tested against FP and SR during the two consecutive rabi seasons (2011-13) at 74 locations in three southern states of Andhra Pradesh, Karnataka and Tamil Nadu. Results revealed that across the three states, grain yield with NE significantly increased by 14 and 6% over FP and SR, respectively (**Table 3**). NE-maize also increased GRF by ₹12,352 and ₹4,430/ha over FP and SR and it reduced the fertiliser cost by ₹2,204 and ₹906/ha over FP and SR, respectively.

Improved maize yields with the use of NE-based fertiliser recommendations could be attributed to the 4R compliant scientific nutrient prescriptions generated by NE, which primarily suggests application of major NPK nutrients using the right fertiliser sources, applied at the right rate and at the right time. NE also suggested application of secondary and micronutrients wherever they were deficient (data not shown) and helped in promoting balanced use of all the essential nutrients in addition to improving yields and optimizing nutrient use. The higher GRF with the use of NE over FP and SR could be attributed to higher maize yields and the associated reduction in fertiliser cost observed with NE-based recommendations. NE provides nutrient recommendations 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/ha in Andhra Pradesh), NE recommends a range of N, P_2O_5 and K_2O application rates within a region depending on attainable yield and expected responses to fertiliser at an individual farmer's field. 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 farmers, simply by providing scientific direction in the most appropriate use of fertilisers with each individual field.

Summary

NE field-specific fertiliser recommendations, demonstrated in the southern region, increased yield and economic benefits through optimised application of nutrients that takes into account variations in the growing environment, affected by climate, soil type, nutrient availability, cropping system, and crop management practices. It estimated the major nutrient requirement for a practical and challenging yield target and the tool also provided secondary and micronutrient recommendations wherever these nutrients are limiting. Besides providing location specific nutrient recommendations, the tool has options to tailor recommendations, based on resource availability to the farmers.

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Nutrient Expert®–Wheat: A Tool for Increasing Crop Yields and Farm Profit

By Sudarshan K. Dutta, Kaushik Majumdar, Vishal Shahi, Anil Kumar, Vinod Kumar, Naveen Gupta, T. Satyanarayana, M.L. Jat, Mirasol Pampolino, and Adrian Johnston

The Nutrient Expert®–Wheat fertiliser decision support tool-based fertiliser recommendation was compared with existing fertiliser management practices in 109 on-farm sites in Punjab, Haryana and Bihar. The tool addressed the spatial and temporal variability in soil nutrient supply as well as the difference in tillage. The tool-based recommendation also improved yield and profitability over farmers' fertilisation practices and State recommended fertiliser rates for wheat.

Nutrient Expert®–Wheat (NE) is a nutrient decision support tool that helps wheat farmers to implement 4R Nutrient Stewardship at their farms. This is particularly useful for smallholder system of South Asia where precise nutrient management in small and marginal farms is a challenge, especially due to the infrastructural constraints for soil testing. NE provides wheat farmers a balanced nutrient recommendation based on the concept of site–specific nutrient management (SSNM). The on-farm application of SSNM entails using a set of nutrient management principles to supply crop nutrient requirements tailored to a specific field or growing environment (Pampolino et al., 2012). It aims to account for indigenous nutrient sources, including crop residues and manures; and apply fertiliser at optimal rates and at critical growth stages to meet the deficit between the nutrient needs of a high-yielding crop and the indigenous nutrient supply. SSNM integrates information from different scales to make field-specific decisions on N, P and K management. Originally based on laboratory analysis of plant nutrient uptake, the method was adapted to use yield responses measured in omission plots compared with NPK.

NE–Wheat for South Asia was developed in consultation with the International Maize and Wheat Improvement Center (CIMMYT), partners from the National Agricultural Research & Extension System, and representatives of stakeholder groups such as fertiliser industry, seed industry and NGOs. The development process of NE–Wheat included data acquisition from current and historical studies from major wheat growing States in India, development of algorithms and decision rules in consultation with partners and stakeholders, and finally validation of the tool across wheat growing regions of the country.

The NE validation trials compared NE–Wheat tool-based fertiliser recommendation with Farmer Fertiliser Practice (FFP) and State Recommendation (SR) in farmers' fields. The NE recommendation for an individual field was used in two treatments based on the splitting of N. NE1 considered N application at three equal splits (33% basal + 33% after 25 days + 33% after 45 days) and NE2 considered N application in two splitting (50% or 80% as basal and 50% or 20% after 45 days).

The on-farm validation trials (n=109) were conducted across major wheat-growing states of India that included Bihar, Haryana and Punjab in the year 2010-11 and 2011-12. The current study reports the data from 53 trials conducted in 2010-11 that included 10 in Bihar, 21 in Haryana, and 22 in Punjab, and 56 trials in 2011-12 in Bihar (n=11), Haryana (n=26), and Punjab (n=19). Among these 109 trials a total of 65 trials were conducted under conventional tillage (CT) and 44 trials (22 trials each year) were conducted under zero tillage (ZT).

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

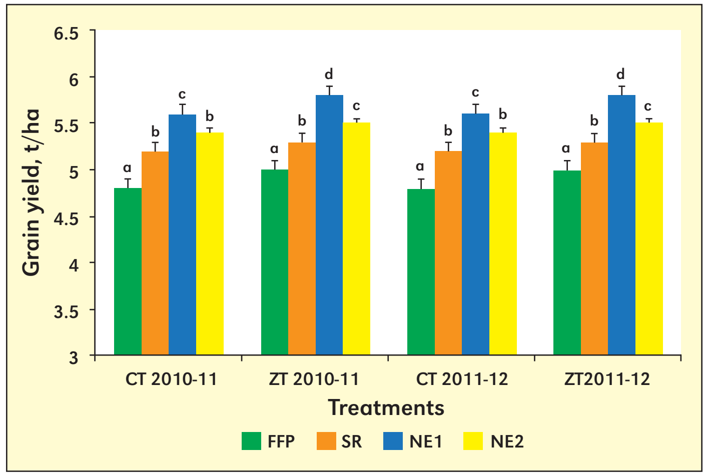

Figure 1. Grain yield of wheat across different nutrient management and tillage practices. Yield with different letters are significantly ($p \leq 0.01$) different.

The present study showed a significant ($p \leq 0.01$) increase in wheat yield through NE1 and NE2 nutrient management treatments over FFP and SR in all the seasons (**Figure 1**) and years. The yield of wheat was higher in ZT over CT across sites and years. In more than 13,500 on-farm trials conducted to evaluate different resource conservation technologies in rice and wheat in India, Nepal and Bangladesh during 2007–2008, reduced-till and zero-till drill-seeded wheat, zero till drill-seeded wheat with residue mulch, broadcast wheat in high-moisture soil without any tillage, and bed-planted drill-seeded wheat—performed better than the farmers' practice of conventional till broadcast wheat (IRRI, 2009).

Wheat yields were significantly ($p \leq 0.01$) higher in NE1 compared to NE2 under both CT and ZT suggesting that an extra split of N helped increase grain yield. Applying N in wheat through three splits (33:33:33) or by two splits (50:50) are common practices among farmers in India. Often the three-split option produces better yields as applications are better matched with high physiological demand stages of the crop (Singh et al., 2002). On the other hand, the two-split option helps save labour cost of applying an extra split, which can be substantial in relatively large fields. However, generally it is observed that two-splits works equally well as three-splits in heavy soils, while three-splits produce better yields in lighter soils (Singh et al., 2002). It is likely that the abrupt increase in wheat yields (**Figure 2**) in the NE1 treatment over all other

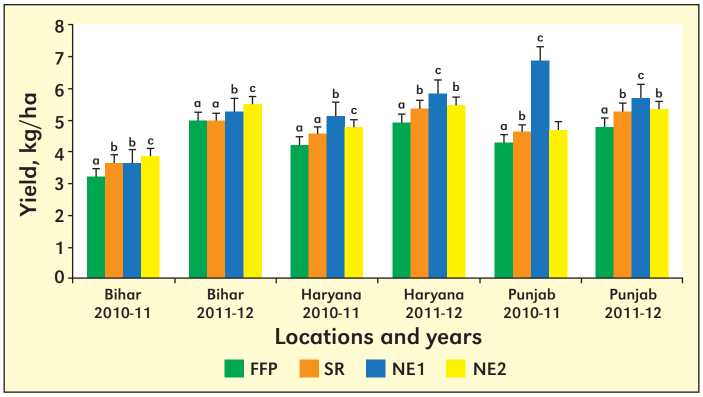

Figure 2. Grain yield of wheat across different nutrient management practices across different states. Yield with different letters are significantly ($p \leq 0.01$) different.

treatments might be due to the light texture of the soils where trials were set up.

While considering the performance of NE across different states, the present study also highlights that both NE1 and NE2 have significantly ($p \leq 0.05$) higher grain yield across the treatments in all the three study states (**Figure 2**). This suggests that nutrient recommendations from NE, generated through proper assessment of growing environment and target yields, were more suitable than generalised state recommendations or practices by farmers based on their perception. Better performance of the NE recommendations over the other practices across a large area in the Indo-Gangetic Plains (IGP) also establishes the efficacy of the tool.

We looked at the difference in nutrient application under different treatments in the three states over two seasons (**Table 1**). In the case of Bihar, N application rates did not differ among the treatments in 2010-11 but FFP rates were higher in 2011-12 than the other treatments. The P_2O_5 application rates were lowest in NE in 2010-11, while there was no significant difference among the treatments in 2011-12. The K_2O application rates were significantly higher with NE than FFP and SR in both the years. In general, nutrient application rates in FFP and NE were comparatively higher in 2011-12 and **Figure 2** shows that yield levels were higher that year than the previous wheat season.

The N application rates in Haryana in 2010-11 were the same for NE and FFP, which were both lower than SR. In 2011-12, however, the NE tool recommended less N than SR or FFP. For P_2O_5, application rates recommended by NE were lower than FFP and SR but the trend reversed in 2011-12 and NE recommended more P than SR and FFP. The K_2O recommendations by NE were higher than FFP and SR in both the years.

The NE tool recommended higher N, P_2O_5 and K_2O than FFP and SR in Punjab in 2010-11. The NE and SR recommended similar rates of N, which was lower than FFP, and P_2O_5 application rate remained the same for all the treatments in 2011-12. Potassium application rates were higher in NE. It is evident that NE recommendations were different in both the years and across states. This suggests that the tool-based recommendations are addressing the spatial, as well as temporal variability, reflecting the farm-to-farm changes in management.

Overall, the N application rates in the FFP treatment were significantly higher than the other treatments across tillage and years (**Figure 3**). The N doses in NE were at par with

Table 1. Fertiliser rates across three different states. Within states dose followed by different letters in superscript are significantly ($p \leq 0.05$) different.

Year	State	Treatments	------ Rates, kg/ha ------ N	P_2O_5	K_2O
2010-11	Bihar	FFP	124^{a}	48^{a}	34^{a}
		SR	120^{a}	60^{b}	40^{b}
		NE1	115^{a}	41^{c}	57^{c}
		NE2	115^{a}	41^{c}	57^{c}
	Haryana	FFP	166^{a}	58^{a}	0^{a}
		SR	150^{b}	60^{b}	60^{b}
		NE1	170^{a}	43^{c}	81^{c}
		NE2	168^{a}	45^{c}	76^{d}
	Punjab	FFP	144^{a}	53^{a}	3^{a}
		SR	125^{b}	62^{b}	30^{b}
		NE1	158^{c}	71^{c}	87^{c}
		NE2	158^{c}	71^{c}	87^{c}
2011-12	Bihar	FFP	142^{a}	64^{a}	33^{a}
		SR	120^{b}	60^{a}	40^{b}
		NE1	128^{b}	64^{a}	78^{c}
		NE2	128^{b}	64^{a}	78^{c}
	Haryana	FFP	174^{a}	58^{a}	2^{a}
		SR	150^{b}	60^{b}	60^{b}
		NE1	140^{c}	63^{c}	86^{c}
		NE2	140^{c}	63^{c}	85^{c}
	Punjab	FFP	142^{a}	64^{a}	33^{a}
		SR	120^{b}	60^{a}	40^{b}
		NE1	128^{b}	64^{a}	78^{c}
		NE2	128^{b}	64^{a}	78^{c}

SR. The P_2O_5 application rates were significantly ($p \leq 0.05$) higher in NE as compared to FFP and SR under both the tillage practices and year (**Figure 4**). The K_2O applications were significantly ($p \leq 0.05$) increased in NE1 and NE2 over FFP and SR at both CT and ZT (**Figure 5**). Farmers in Punjab, Haryana and Bihar generally neglect K application in wheat. Potassium application in rice-wheat system, that is prevalent

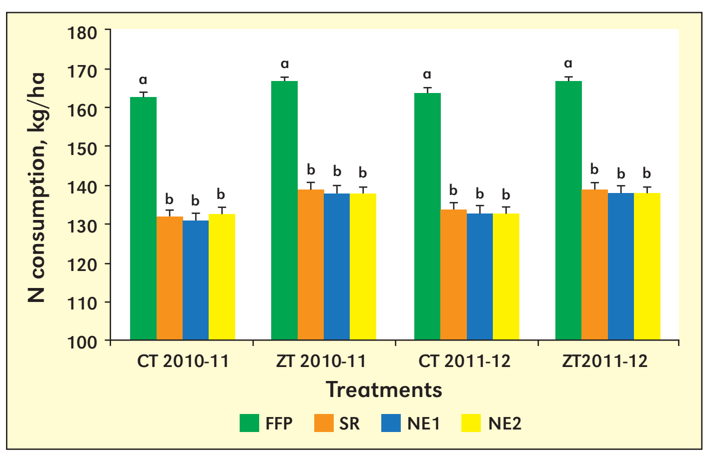

Figure 3. Fertiliser N rates across different treatments while considering all the locations. Rates with different letters are significantly ($p \leq 0.05$) different.

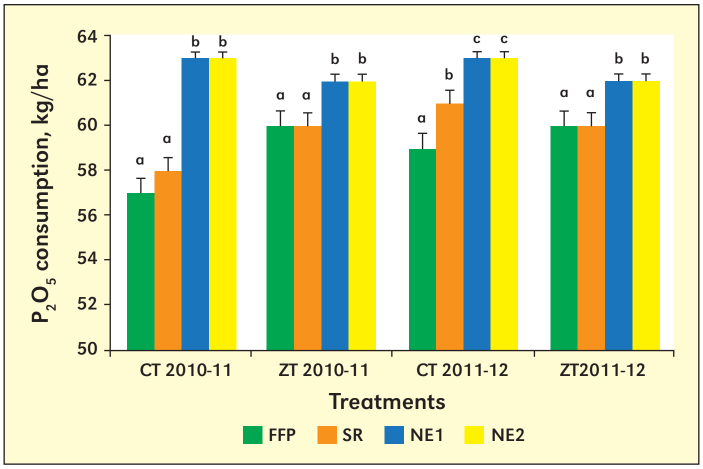

Figure 4. Fertiliser P_2O_5 rates across different treatments while considering all the locations. Rates with different letters are significantly ($p \leq 0.05$) different.

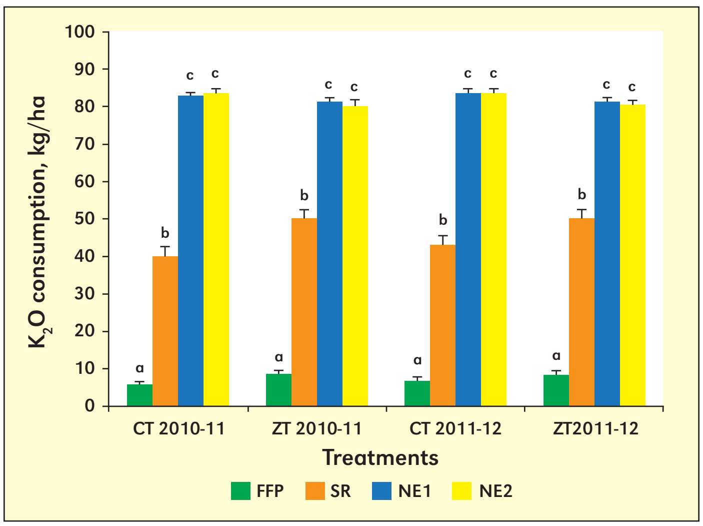

Figure 5. Fertiliser K_2O rates across different treatments while considering all the locations. Rates with different letters are significantly ($p \leq 0.05$) different.

in these three states, is far below the required amount. The NE tool, while assessing the cropping system nutrient balance identified a large deficit in K application and recommended high rates to reduce the negative (input-output) K balance in the fields.

Economics

The benefit:cost (B:C) ratios of the treatments were estimated using the cost of inputs and value of the output. The results were represented considering the B:C ratio of the FFP treatment as a unit (**Figure 6**). Both the NE treatments and the SR increased the economic benefit over FFP.

Results showed that the B:C ratio of NE1 were higher than

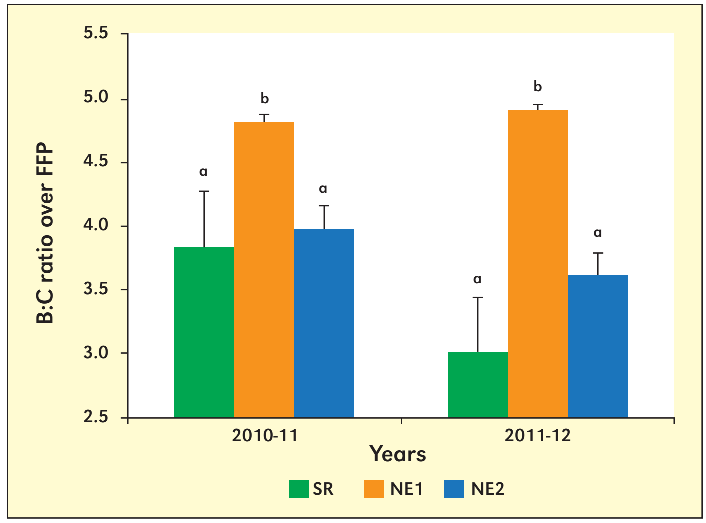

Figure 6. Benefit:Cost ratio over FFP. Ratio with different letters is significantly ($p \leq 0.05$) different. Cost of N: ₹12/kg (on the basis of Urea); Cost of P_2O_5: ₹45/kg (on the basis of single superphosphate); Cost of K_2O: ₹27/kg (on the basis of potassium chloride); Value of maize grain: ₹11/kg.

that of SR and NE2 in both 2010-11 and 2011-12 cropping years (**Figure 6**). A combination of appropriate rate estimation and better splitting of the nitrogen improved yield in the NE1 treatment over the other practices.

Summary

NE–Wheat validation trials in the year 2010–11 and 2011–12, across three different states of the Indo-Gangetic plains, showed that the NE tool-based fertiliser recommendation increased wheat yield and economic benefit for farmers. Large-scale implementation of the tool provides the opportunity to bridge nutrient-related yield gaps in wheat and increase farm profitability in an environmentally sustainable manner. BC-SA

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Nutrient Expert® Improves Maize Yields while Balancing Fertiliser Use

By Vishal B. Shahi, Sudarshan K. Dutta, Kaushik Majumdar, T. Satyanarayana, and Adrian Johnston

Nutrient Expert® (NE) is a simple and rapid tool for generating field-specific fertiliser recommendations. Results from 17 on-farm sites in five districts of Bihar showed that NE significantly increased maize yields and economic returns compared to the generalized State Recommendation (SR) and Farmers' Fertilisation Practice (FFP). NE's impact on fertiliser use in maize shifted N and K application upwards while also lowering P application rates.

Bihar is one of the predominant maize-growing states in India as it produces about 9% of the country's total. But average maize yields in the state are much lower than their potential. One of the reasons for low maize yields is the lack of appropriate and balanced nutrient management strategies, especially for the recently introduced maize hybrids. Existing fertiliser recommendations in the state are also homogeneous in nature—prescribing a single rate of fertiliser for large areas without giving consideration to the variability in soil fertility that exists across farmers' fields. This has led to unsustainable use of fertiliser and the associated economic and environmental concerns. Fertiliser is a critical input in maize production, and its rational use is expected to improve productivity and economics of production while reducing the environmental footprint.

Bihar farmer proudly shows his excellent end result of implementing a Nutrient Expert® fertiliser recommendation.

The principles of SSNM for maize have been integrated into a user-friendly decision support tool called Nutrient Expert® (Pampolino et al., 2012). The tool was developed for the South Asia Program of the International Plant Nutrition Institute (IPNI) in collaboration with the International Maize and Wheat Improvement Center (CIMMYT) to facilitate large-scale implementation of SSNM in farmers' fields. The software configuration is described in detail by Xu et al. (2014). The tool starts by asking a few simple questions to determine attainable yield and yield responses to fertiliser. It can work with or without soil testing, and can provide field-specific nutrient recommendation to millions of smallholder farmers who might not have access to soil testing, especially for multiple cropping systems. The tool integrates 4R Nutrient Stewardship principles (i.e., ensuring the right source is applied at the right rate, right time, and right place) into a fertiliser recommendation and suggests different levels of application rates based on varying target yields as well as growing environments. More importantly, it considers the environmental, economic and agronomic benefits simultaneously.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; SSNM = site-specific nutrient management; ₹1 = US$61. Project #IPNI-2010-IND-509

The performance of Nutrient Expert® (NE) was evaluated in Bihar State by comparing its results against the SR and FFP. These on-farm experiments examined grain yield, economic returns, and NPK fertiliser use in 17 farmers' fields across five districts (Samastipur, Patna, Begusarai, Jamui, and Purnia) with winter maize during 2011 to 2012. The individual treatment plot size was 100 m^2 or higher. The SR treatment included uniform application of 120-60-40 kg N-P_2O_5-K_2O/ha. Farmers chose hybrid maize varieties with yield potentials above 5 t/ha. The seed rate for all treatments was chosen to

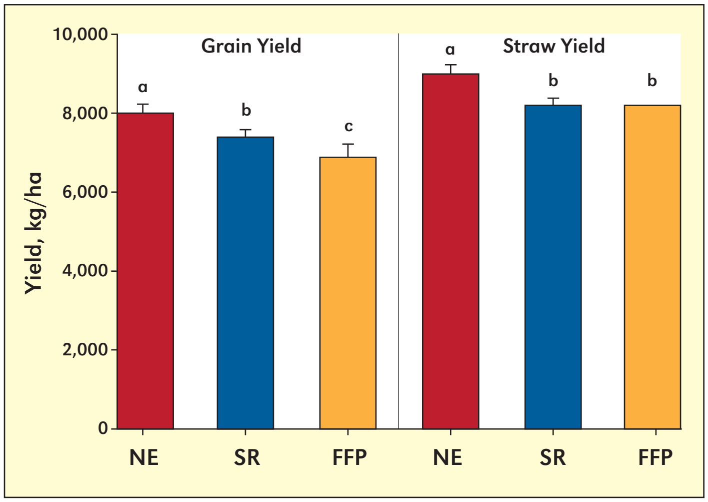

Figure 1. Average (n =17) grain and straw yields of maize in Nutrient Expert® (NE), State Fertiliser Recommendation (SR) and Farmer Fertilisation Practice (FFP) treatment plots. Yield component numbers with different letters are significantly different at $p \leq 0.001$.

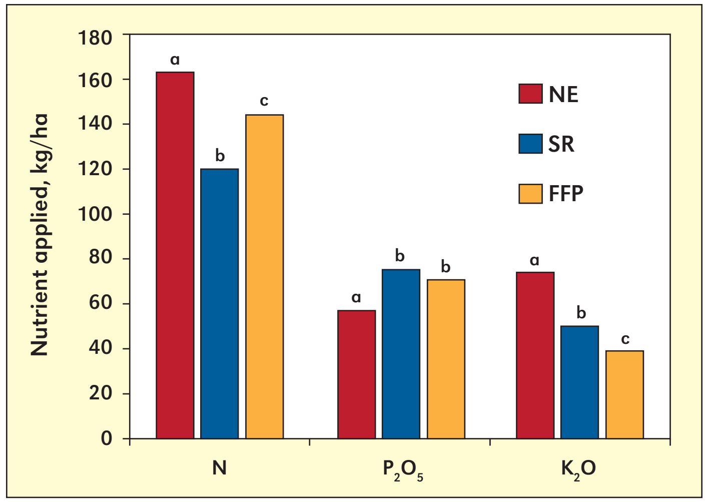

Figure 2. Average (n =17) N, P_2O_5 and K_2O applied in Nutrient Expert® (NE), State Fertiliser Recommendation (SR) and Farmer Fertilisation Practice (FFP) treatment plots. Numbers within each nutrient with different letters are significantly different at $p \leq 0.05$.

maintain a planting density of 65,000 to 85,000 plants/ha. Similar water management and plant protection measures were adopted for all treatments at each site. At harvest, the sampling area (located within the middle part of the plot) was selected randomly in each treatment plot to determine grain yield. Grain yields from all treatment plots were calculated at 15.5% moisture content.

The Impact of NE on Maize

Results suggested that both grain yield and the total biomass yield in NE-based fertiliser recommendation plots were significantly higher compared to SR and FFP treatments (**Figure 1**). The average grain yields were 8, 7.4 and 6.9 t/ha in NE, SR and FFP plots, respectively, which indicated a 10 to 15% increase in maize grain yield when using NE. Xu et al. (2014) achieved similar results in more than 400 on-farm trials conducted throughout China.

Similar to grain yield increases, NE plots showed significant increase in gross returns over fertiliser cost compared to SR and FFP treatment plots (**Table 1**). Also, there was either no change or no significant increase in farmers' fertilisation cost in NE plots compared to SR and FFP plots.

Table 1. Average economic return to farmers' resulting from fertilisation.

Nutrient Expert®	State recommendation	Farmer's practice
Gross return on investment, Rs/Re		
14a	13b	13b
Net return on investment, Rs/Re		
13a	12b	12b

2011/12 Costs/Prices: Urea = ₹12/kg N, SSP = ₹45/kg P_2O_5, KCl = ₹27/kg K_2O, Price of maize grain: ₹11/kg.
Numbers within rows with different letters are significantly different at $p \leq 0.07$.

The average recommended N and K_2O were significantly higher with NE, while the average recommended P_2O_5 was significantly lower, compared to SR and FFP (**Figure 2**). Fertiliser N application in FFP ranged from 105 to 188 kg/ha, with an average of 144 kg/ha across different trial sites. Similarly, P_2O_5 application rates in FFP ranged from 39 to 147 kg/ha, with an average of 71 kg/ha, while K_2O application rates varied from 0 to 107 kg/ha, with an average value of 39 kg/ha. The NE-based fertiliser recommendation suggested an N application range between 130 and 190 kg/ha, P_2O_5 application between 44 and 64 kg/ha and K_2O application between 55 and 105 kg/ha, with average values being 163-57-74 kg N-P_2O_5-K_2O/ha. The ranges of nutrient application rates narrowed with NE compared to FFP, which suggested that NE was able to better manage the variability in growing environments in Bihar and can therefore be a reliable tool for site-specific fertiliser application.

Summary

Nutrient Expert® enables farmers to dynamically adjust fertiliser application rates based on crop requirement, growing environment, and target yield in their fields, which resulted in better maize yields and economic returns in Bihar, while also balancing fertiliser use compared to FFP and SR. We expect that the user-friendliness of NE and its robust estimation of site-specific nutrient recommendation will be attractive to Bihar extension specialists working with its 1.5 million farmers and their intensively cultivated maize areas. BC-SA

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Precision Nutrient Management in No-till Wheat: A Case Study for Haryana

By Tek B. Sapkota, Kaushik Majumdar and M.L. Jat

Given the current poor understanding of nutrient management in no-tillage-based wheat production in Haryana, the authors compared various available strategies. Nutrient Expert®-based fertiliser recommendation supplemented with GreenSeeker™-guided N application produced higher grain yield and economic return and reduced the global warming potential (GWP) of wheat production as compared to other nutrient management practices in seven districts of Haryana.

Wheat is the second most important cereal crop in India occupying about 29 million ha area and contributing 37% to the total foodgrain production. Nearly 50% of the total wheat production in India comes from the Northwestern (NW) plain zone (Majumdar et al., 2013). Surveys done in this region have revealed that farmers often apply greater than recommended rates of fertiliser N and P, but ignore the application of K and other secondary and micro-nutrients (Singh et al., 2013). This leads to reductions in crop yield, nutrient use efficiency and farmer profit and also increases environmental risks associated with the loss of unutilised nutrients through gaseous emissions or leaching. The Intergovernmental Panel on Climate Change (IPCC) loosely assumes that 1% of fertiliser N applied in the field is emitted as N_2O, but this fraction can be much higher in areas with imbalanced fertilisation like in NW India.

Recent advances in the development of precision nutrient prescription tools like Nutrient Expert® (NE) decision support system (Pampolino et al., 2012), GreenSeeker™ (GS) handheld sensors and leaf colour charts (LCCs) have shown promise in increasing crop productivity and nutrient use efficiency of crops and minimising the environmental footprint (Satyanarayana et al., 2012).

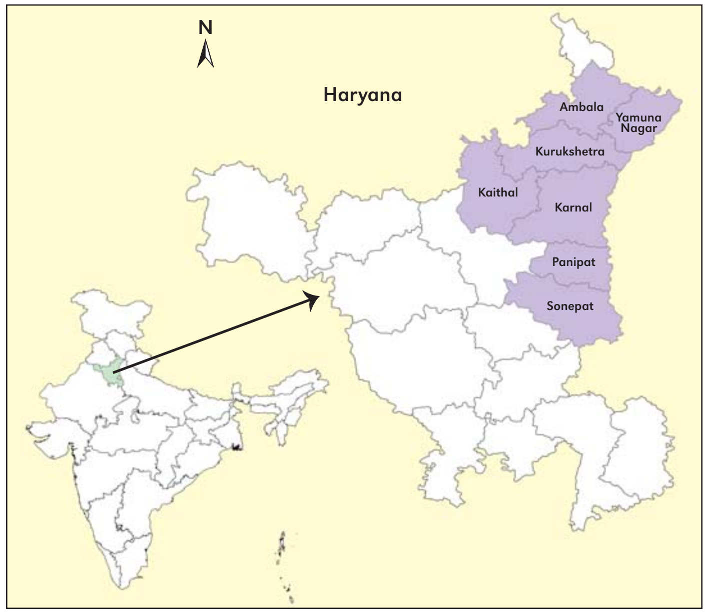
In a collaborative effort between the International Maize and Wheat Improvement Center (CIMMYT) and the International Plant Nutrition Institute (IPNI) to test, pilot and upscale NE-based fertiliser management, on-farm participatory research was conducted in seven districts (Karnal, Kurukshetra, Kaithal, Ambala, Sonepat, Panipat, and Yamunanager) of Haryana to evaluate and compare NE-based strategies in conventional and no-till wheat production systems. For this, 15 on-farm experiments were established in 2010-11 and 2011-12. The four nutrient management treatments compared included: (1) NE-based recommendation; (2) NE+GS: NE recommendation supplemented with GS-guided application of N; (3) SR: state fertiliser recommendation and (4) FFP or the farmers fertilisation practice. These treatments were compared for agronomic productivity, economic profitability and total greenhouse gas emissions. Total greenhouse gas emissions from wheat production were estimated using the Cool Farm Tool (Hillier et al., 2011). This tool uses information about soil and climatic characteristics, tillage and residue management, crop management practices such as fertiliser and pesticide applications, energy use and total output.

Grain Yield and Economic Profitability

Averaging data for two years, results showed that the highest grain yields were obtained using NE-based nutrient management (NE and NE+GS) strategies followed by SR and FFP (**Figure 1**). Grain yields were not significantly different between NE and NE+GS. Similarly, net returns were also significantly different among various nutrient management strategies. However, net return was not different significantly among NE, NE+GS and SR (**Figure 1**). The total cost of production was not significantly different among the different nutrient management strategies tested (data not shown). Therefore, lower grain and straw yield were mainly responsible for lower net returns under FFP as compared to other nutrient management strategies.

Imbalanced fertiliser application due to non-application of fertiliser K (Sapkota et al., 2014) was probably the main reason for lower grain yield under FFP compared to other treatments. Nutrient recommendations in NE-based strategies were derived after accounting for the native nutrient supplying capacity of soil, nutrient balance in the concerned field at the cropping system level and yield target and therefore, were possibly more balanced compared to the other treatments.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; ₹1 = US$61.



Study districts in the Haryana state.

Global Warming Potential

Estimated GWP, as affected by nutrient management strategy, was significant for both GWP per t wheat yield and GWP per US$ net return. For example, FFP resulted in higher GWP per t of wheat yield whereas NE-based recommendation followed by GS-based N application resulted in the lowest GWP per t of wheat (**Figure 2**). A similar trend was observed for GWP per US$ of net return.

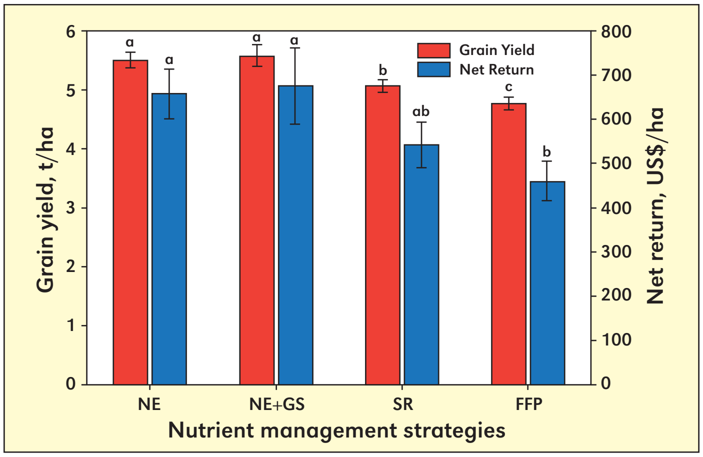


Figure 1. Wheat grain yield and net returns under no-tillage system as affected by different nutrient management strategies in Haryana. [The data is the mean of two years from 15 farmers' fields (i.e., n=30). Means followed by different letters within same variable are significantly different based on LSD$^{0.05}$. Vertical bars show standard errors of the means. NE: Nutrient Expert®, NE+GS: Nutrient Expert® supplemented with GreenSeeker, SR: State recommendation, and FFP: farmers' fertiliser practice.]

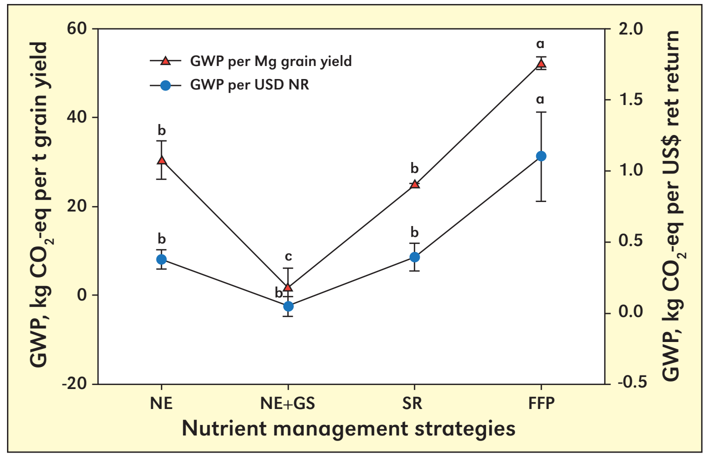


Figure 2. Total Global Warming Potential (GWP) per t grain yield and per US$ net return (NR) under different nutrient management strategies in no-till wheat production systems in Haryana. [The data is the mean of two years from 15 farmers' fields (i.e., n=30). Means followed by different letters within same variable are significantly different based on LSD$^{0.05}$. Vertical bars show standard errors of the means. NE: Nutrient Expert®, NE+GS: Nutrient Expert® supplemented with GreenSeeker, SR: State recommendation, and FFP: farmers' fertiliser practice.]

Table 1. Cost of key inputs and outputs used for economic analysis during two wheat growing seasons.

Particulars	2010-11	2011-12
Minimum support price of wheat grain, ₹/kg	11.20	12.85
Market price of wheat straw, ₹/kg	2.50	2.50
Labour wage, ₹/person/day	150 to 200	200 to 250
Urea, ₹/kg	4.70	5.36
Diammonium phosphate, ₹/kg	10.00	18.20
Murate of Potash, ₹/kg	9.00 to 10.00	11.00 to 12.00
Zinc sulphate, ₹/kg	20.00	25.00
Seed, ₹/kg	16.25	18.00
Seed treatment, ₹/kg	1.25	1.25
Diesel cost, ₹/L	36.49	39.92
Electricity charge, ₹/kWh	0.30	0.30
Hiring cost of harrow/tiller, ₹/ha/pass	550 to 625	750 to 800
Planking cost, ₹/ha/pass	250 to 375	350 o 500
Land rent, ₹/ha/season	35,000	37,500
Interest on working capital, percent/year	12.00	12.00

Broadcast application of relatively larger amounts of N fertiliser under FFP was mainly responsible for higher total GWP as compared to other nutrient management strategies. Further, lack of K fertiliser in FFP probably reduced recovery of other nutrients by wheat, thereby reducing yield. This ultimately resulted in higher GWP per unit of produce under FFP. Our estimates show that no-till wheat production under a NE-based recommendation supplemented with GS-guided N management can be carbon neutral both in terms of yield and net return. This effect can be attributed to better nutrient use efficiency from in-season precision N application (i.e., rate and number of split applications matching the physiological demand of wheat). This probably reduced residual nitrate-N in soil profile, thereby minimising the N loss in the form of N_2O emissions.

Summary

Both grain yield and net return were higher with NE-based strategies compared to FFP and SR. The estimated total carbon footprint (i.e., GWP per t of wheat grain production and per US$ of net return) was also lower for NE-based strategies than other nutrient management strategies. Thus, the use of precision nutrient management tools such as NE and GreenSeeker is important for increasing wheat yields and farmer profits yet minimising the environmental footprint of wheat production.

Acknowledgements

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Integrating Biophysical and Socio-economic Determinants into Field-specific Fertiliser Recommendations

By Hirak Banerjee, Rupak Goswami, Somsubhra Chakraborty, Sudarshan Dutta, Kaushik Majumdar, T. Satyanarayana, M.L. Jat, and Krishnendu Ray

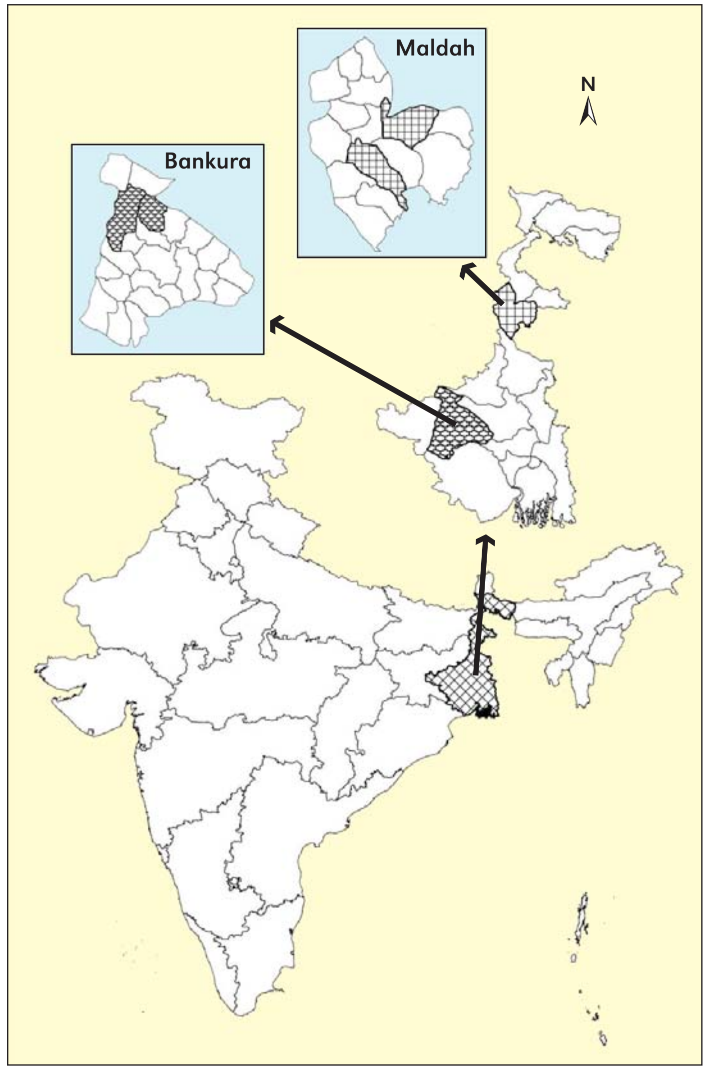
Socio-economic conditions of smallholder farmers, and their resource endowment, plays a major role in fertiliser application decisions in maize. The use of Rapid Rural Surveys in the present work helped identify distinct typologies of maize farmers from West Bengal in Eastern India. Farmer-specific fertiliser recommendations from the Nutrient Expert® tool, integrating biophysical and socio-economic determinants, helped improve maize productivity for different farm typologies.

Maize farming in eastern India is dominated by smallholder farmers, operating under a wide range of soil, climate, and socio-economic conditions. Farmer resource endowment plays a potentially important role in determining profitability of maize production systems (Banerjee et al., 2014). Addressing the low productivity of maize in the region requires identification of yield-limiting factors in different socio-economic settings and characterization of farm typologies (classifications) for targeting site-specific management interventions. Farm typology recognizes that farmers are not a monolithic group and face different constraints in their farming decisions based on available resources and their lifestyle (Soule, 2011). Grouping farmers within a domain in different typologies is an essential step in realistic evaluation of the constraints and opportunities that exists within farm households for appropriate interventions. The present study was initiated to identify different typologies of smallholder maize farmers in Eastern India.

Farm typologies were determined on the basis of information derived from surveys conducted in Bankura and Malda districts of West Bengal. The two districts represented two distinct agro-ecological zones of the state and are representative of a large part of eastern India in terms of farmer socio-economic conditions and bio-physical characteristics of their farmlands. Structured interviews with a standardized questionnaire were conducted in 180 farms (90 farms per district). Survey questionnaires were designed to capture bio-physical, socio-economic, and managerial aspects of farming. A database was created and screened to eliminate outliers in the dataset—167 entries were retained in the database. This information, along with relevant reviews of literature, nature of data, and initial data analysis led to a selected set of variables which were used in classification and regression tree (CART) analysis. We hypothesized that farmer typology driven fertiliser recommendations based on the Nutrient Expert® for Maize (NE) fertiliser decision support tool (Pampolino et al., 2012) would be able to improve farmers' yield and profitability in smallholder maize systems of Eastern India.

Results and discussion

During descriptive analysis, categorization of the dataset was essential to explain the variability arising from multiple interactions among socio-economic, crop management, and infrastructural variables. For this, we employed three regression tree analyses for maize grain yield—with total (*kharif* + *rabi*) productivity as the target variable. First, the whole dataset was used for CART analysis (n = 167), with total maize grain yield as the target variable. CART identified seed rate as the main factor explaining yield variability (**Figure 1**). Maize farmers who used less than 28 kg/ha (Node 2, n = 137) seed produced an average maize grain yield of 3.9 t/ha; whereas, farms where seed rates were more than 28 kg/ha achieved an average yield of 2.3 t/ha (Node 8; n = 30). Node 8 is further split by farm size, with less than 0.5 ha farms yielding 1.2 t/ha (TN 8, n = 13) on an average and farms of more than 0.5 ha yielding 3.2 t/ha (TN 9, n = 17). Node 2 is further split into the type of seed used. Seed type 3 (traditional seed type) produced a mean yield of 0.6 t/ha (TN 1, n = 5); whereas seed type 1 and 2 (composite and hybrid seeds) yielded 4 t/ha (Node 3, n = 132). This node



Study locations (Districts) within West Bengal.

Abbreviations and notes: P = phosphorus; K = potassium; TN = terminal node; ₹1 = US$61.

is, in turn, again split by seed rate. Plots where less than 18 kg/ha seed was used yielded average 3.5 t/ha (Node 4, n = 60); whereas, an average yield of 4.4 t/ha was achieved when more than 18 kg seed/ha (Node 6, n = 72) was used. Interestingly, it was observed that seed rate had multiple threshold values that reappear as splitting criteria indicating its multi-modal distribution in the dataset. Node 4 is further split by total labour. An average yield of 3.1 t/ha was recorded (Node 5, n = 45) when less than 47 man days were used in maize production; the mean yield increased to 4.9 t/ha (TN 4, n = 15) when more man days were employed for cultivation. Node 5 is split by total investment, with investment less than ₹900/ha resulting in a yield of 2.6 t/ha (TN 2, n = 34) and investment in excess of that resulted 4.5 t/ha of yield (TN 3, n = 11). Node 6 was split by organic manure. When less than 5.8 t/ha organic manure was used, a yield of 4.1 t/ha (Node 7, n = 56) was observed; the average yield increased to 5.9 t/ha (TN 7; n = 16) with higher application of organic manure. Node 7 was split by "plant-to-plant" spacing of maize; average maize yield was 3.4 t/ha (TN 5, n = 31) when spacing is less than 28 cm. Mean yield of 4.9 t/ha (TN 6; n = 25) was recorded with higher spacing.

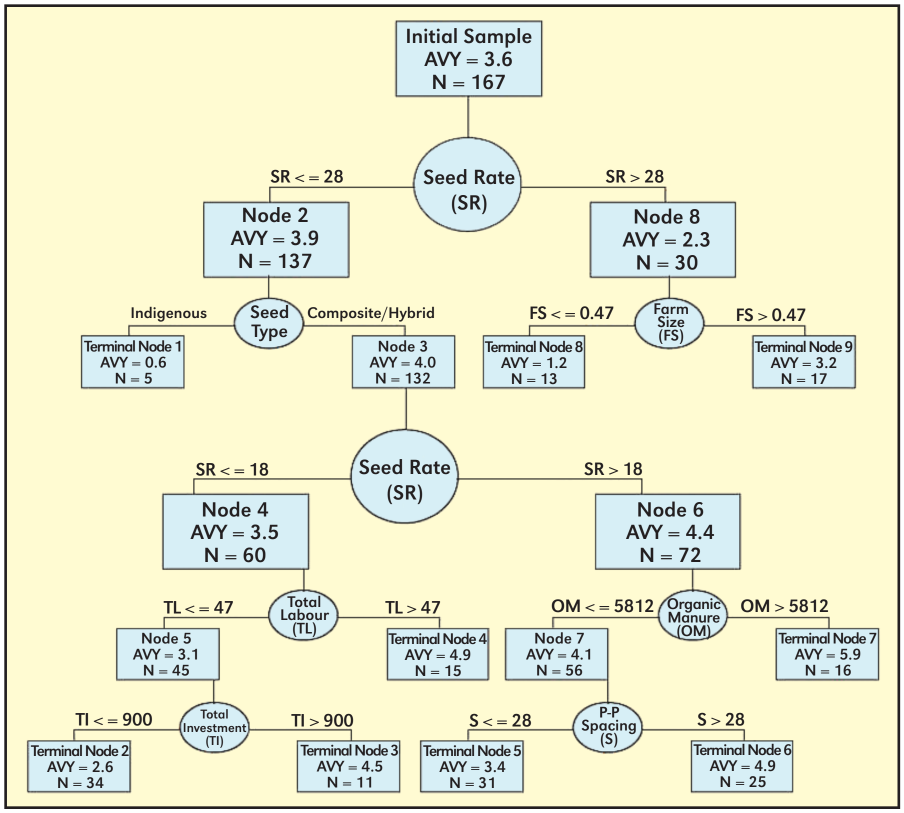


Figure 1. Classification and regression tree models to describe maize grain yield as a function of variables describing agronomic management and socio-economic conditions. Each splitting variable is associated to a threshold value in its own units that separate the larger group of data in two subgroups. In the square box the AVY value is the average yield of the group and the n value corresponds to the number of observations contained in that group.

The highest and lowest yield classes represented in different nodes of the regression trees (**Figure 1**) were used to compare the mean values of different splitting variables in these nodes (**Figure 2**). Comparing the lowest and highest yields for overall maize grain yield (TN 8 and TN 7, respectively) revealed that highest yield was obtained because of sowing hybrid seed (and not traditional type), higher seed rate (30 kg/ha against 25 kg/ha), higher farm size (1.0 ha against 0.6 ha), lower total man days used (34 man days against 39 man days), higher investment in maize cultivation (₹5,400/ha against ₹2,300/ha), higher organic manure application (4.2 t/ha against 3.4 t/ha) and higher plant-to-plant spacing (30 cm against 25 cm) (**Figure 2**). These differences led to a yield gap of 4.7 t/ha.

Apart from explaining yield variability in maize, the CART analysis also helped to identify probable farm typologies in the study locations. Taking the whole dataset together and maize yield as the target variable, we identified six farm types from 9 TNs (**Figure 2**). Farm Type – I represented farms that use indigenous maize seed with low seed rate. These were the tribal farmers growing maize for cattle feed and subsistence purpose only. Subsequently, Farm Type – II represented farms that use low seed rate of improved varieties and employed less labour and capital. These were typical resource-poor smallholders of the region and grow maize for subsistence. Farm Type – III

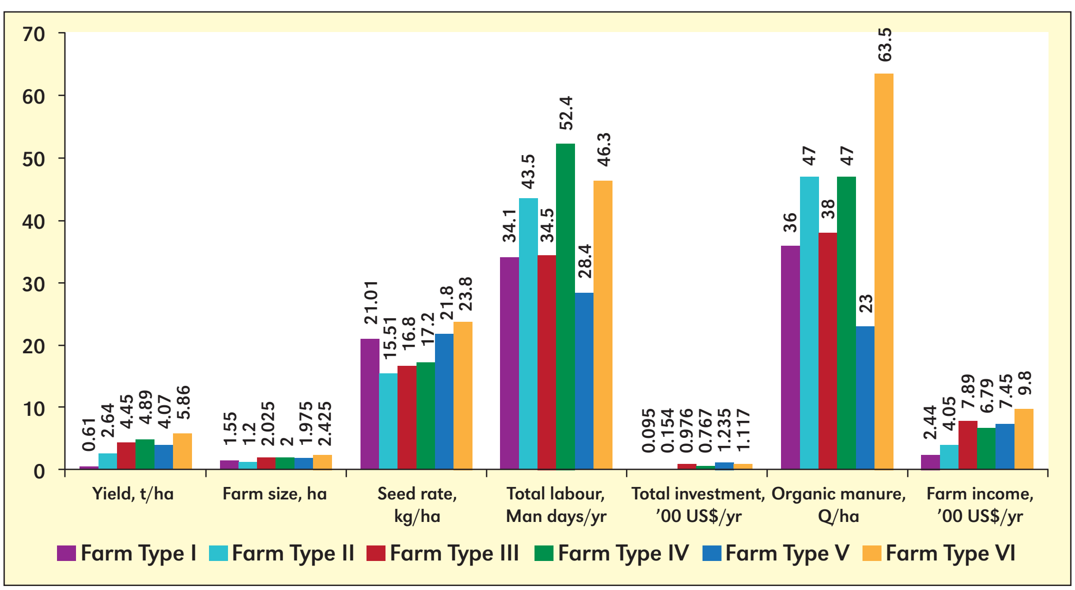


Figure 2. Comparison of Farm Types in terms of selected splitting criteria used in regression tree analysis. Units have been transformed for better visual representation.

was another group of farms with higher investment in maize and represented resource-rich farmers operating under input-intensive and non-labour intensive systems. Farm Type – IV was typical family farms that employed more human labour than others. Farms that used higher seed rate of improved varieties and applied relatively less organic manure constituted another farm type (Farm Type – V). Finally, another farm type that belonged to resource rich farmers employing both inorganic and organic nutrient sources and achieved highest yield constituted Farm Type – VI.

It is important to highlight that nutrient management had a highly significant effect on maize yield in all farm types. As a result, nutrient management was not included in the CART analysis shown in **Figure 1**, as this would have resulted in all other factors being insignificant. The impact of nutrient management is highlighted in **Table 1**, showing the "Total Investment", which is largely influenced by the cost of fertiliser.

As a test case, the effectiveness of applying NE-based fertiliser recommendation over farmers' fertiliser practices (FFP) was tested in a different set of farmers in the South 24 Pargana District of West Bengal. A total of 17 maize-growing farmers were surveyed and were grouped based on their varying existing yield status that ranged from 1.5 to 4.9 t/ha. Two groups of farmers were formed - one with last year (i.e., 2013) average yield of 2.8 t/ha (Type I) and the other group with last year average yield of 4.2 t/ha (Type II). The NE-based recommendations were given to all these farmers in the two different groups. It was observed that the maize grain yield achieved through NE-based fertiliser recommendation was significantly ($p \leq 0.05$) higher in both the types of farmers

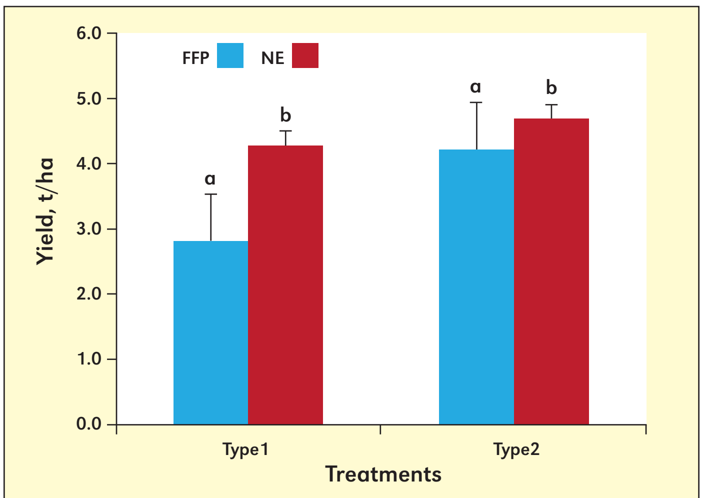


Figure 3. Maize yield at farmers field with Farmer Fertilization Practice (FFP) and Nutrient Expert® (NE) treatments at two different groups of farmers. For comparisons within farm types, columns with different letters are significantly different at $p \leq 0.05$.

(**Figure 3**). Moreover, the average total fertiliser costs were significantly ($p \leq 0.01$) less using NE in both Type I (₹3,552/ha) and Type II (₹4,722/ha) over FFP for Type I (₹4,861/ha) and Type II (₹6,681/ha) farmers (**Table 1**). This is mainly due to significant ($p \leq 0.01$) reduction in P application in the NE plots for both Type I and Type II farmers. It is interesting to see that although there was significant increase in K fertiliser consumption, still there is significant decrease in fertiliser cost for both types of farmers. Also, the Return over Fertiliser Investment (ROI), return per unit invested on fertiliser, was significantly ($p \leq 0.01$) higher in the NE plots over the FFP plots, from ₹5.83 to ₹15.28 for Type I, and from ₹7.75 to ₹12.45 for Type II farmers, respectively.

Table 1. Agronomic and economic performance of Nutrient Expert® (NE) over Farm Ferilization Practice (FFP) for hybrid maize.

Type of Farmer	Parameter	Unit	FP	NE	NE – FP	
Type I	Grain yield	t/ha	1.9	4.4	2.5	***
	Fertiliser N	kg/ha	71	111	40	**
	Fertiliser P_2O_5	kg/ha	72	29	- 43	***
	Fertiliser K_2O	kg/ha	29	35	6	ns
	Fertiliser cost	₹/ha	4,861	3,552	-1,309	**
	ROI[1]	₹/ha	5.83	15.28	9.45	***
Type II	Grain yield	t/ha	3.7	4.7	1.0	***
	Fertiliser N	kg/ha	150	129	- 21	ns
	Fertiliser P_2O_5	kg/ha	81	35	- 46	**
	Fertiliser K_2O	kg/ha	45	60	15	**
	Fertiliser cost	₹/ha	6,681	4,722	- 1,959	**
	ROI[1]	₹/ha	7.75	12.45	4.69	***

***, ** denote significance at <0.001, and 0.01 levels; ns = not significant; [1]ROI = Rupee received per rupee invested. Cost of N: ₹12/kg (on the basis of Urea); Cost of P_2O_5: ₹45/kg (on the basis of SSP); Cost of K_2O: ₹27/kg (on the basis of MOP); Value of maize grain: ₹11/kg.

Conclusions

Results from the present study highlight that the farm survey is an effective tool in delineating farmer typology. The survey conducted in the two different agro-ecological zones of West Bengal helped identify socio-economic and bio-physical determinants for yield gap and yield variations among farms across growing seasons. NE-based fertiliser recommendation for two different farm typologies significantly ($p \leq 0.05$) improved yield and profitability over existing farmers' fertilization practices with less input cost. These results highlight that the NE tool-based fertiliser recommendations can successfully increase productivity and profitability of smallholder maize farmers, operating under a wide range of soil, climate, and socio-economic conditions. BC-SA

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Nutrient Expert®-based Fertiliser Recommendation Improved Wheat Yield and Farm Profitability in the Mewat

By Shashikant N. Bhende and Ashish Kumar

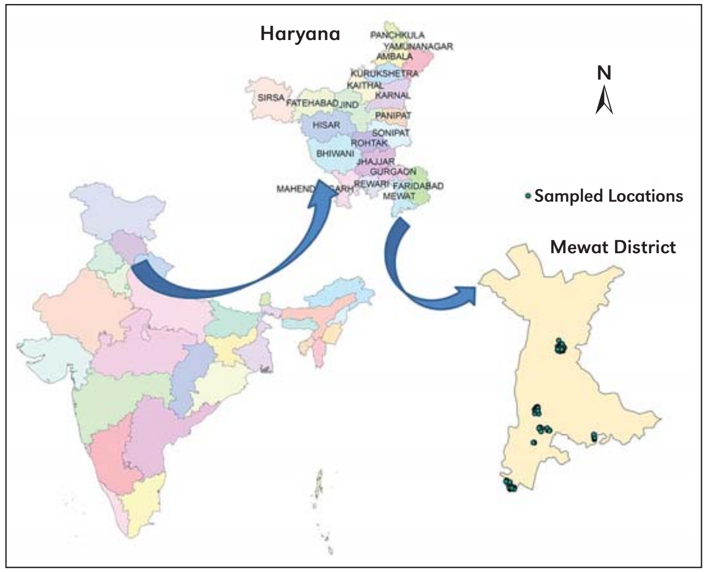
Nutrient Expert® was used to formulate and evaluate improved fertiliser management for wheat farmers in the Mewat region of Haryana. The resulting fertiliser recommendation produced higher yield and farm profit as compared to the farmers' fertilisation practices at a similar partial factor productivity of applied nutrients.

Mewat is a resource-challenged district in Haryana, where rain-fed agriculture is the main source of livelihood. The major cropping systems in Mewat are Pearl millet/Sorghum–Wheat, Fallow/Mustard, Guar–Wheat and Guar–Mustard. Mustard and wheat are the main crops in *rabi* season, which occupy 27,760 ha and 100,536 ha, respectively with an average productivity of 1.3 and 3.5 t/ha. In the *kharif* season, pearl millet is the major crop occupying 26,159 ha with the productivity of 1.3 t/ha.

Soils of Mewat district are generally deficient in most essential macro- and micro-nutrients (IRRAD, 2011). Average productivity of the main crops in the region, viz. mustard, wheat and pearl millet is lower than the state average productivity of these crops. Conventional farming practices, coupled with imbalanced application of nutrients are some of the major reasons for low crop productivity. This has made agriculture unprofitable for most farmers. Improved fertiliser management practices that necessarily include the use of balanced fertilisers, combined with the knowledge on how to adopt these practices, are required to improve crop productivity in the region.

Mosaic, a leading fertiliser producer of the world, lauched the "Krishi Jyoti" project in the Mewat region under its Corporate Social Responsibility (CSR) program in 2008-09. "Krishi Jyoti" (meaning "enlightened agriculture") aimed to improve the livelihood of farmers by helping them achieve enhanced farm profit through improved crop management practices.

The Nutrient Expert® (NE) fertiliser decision support tool for wheat, developed by the International Plant Nutrition Institute and its partner organisations, were used in the Krishi Jyoti project to help improve wheat yield in the region. NE is an easy-to-use, interactive computer-based decision tool that can rapidly provide nutrient recommendation for an individual farmer's field in presence or absence of soil testing data (Pampolino et al., 2012).



Geographical location of Mewat district and sampling locations.

NE-based recommendations were implemented in two

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

Farmers meet to discuss results of implementing Nutrient Expert® as a fertiliser recommendation tool in wheat.

consecutive wheat seasons, 2012-13 and 2013-14, in 40 and 60 farmers' fields, respectively. The farmers were chosen randomly from ten villages of the region. The most commonly grown wheat varieties (i.e., PBW343, PBW711 and PBW2329) of the area were sown in the first fortnight of November in both the years. Each farmer's field was divided into two separate sections. NE-based fertiliser recommendations were applied in one part of the field while existing farmers' fertilisation practice (FFP) was followed in rest of the field. The required amount of N, P and K were applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP), while Zn and S were applied through zinc sulphate and bentonite-S sources.

The entire amount of P, K, Zn, and S were applied at crop establishment, while N was applied three times at 0, 20 to 25, and 40 to 45 days after sowing with one-third of the total amount applied at each split. Wheat varieties and all other management practices remained the same for both treatments in each farmer's field. The crop was harvested in the month of May of the following year and wheat grain yield from the NE and FFP treated plots were recorded based on the whole plot yield.

The yield in FFP plots (n=100) ranged from 2,750 to 5,500 kg/ha, with an average yield of 3,773 kg/ha. The average NE plot yield (n=100) was 5,226 kg/ha, with a range of 4,000 to 6,500 kg/ha (**Figure 1**).

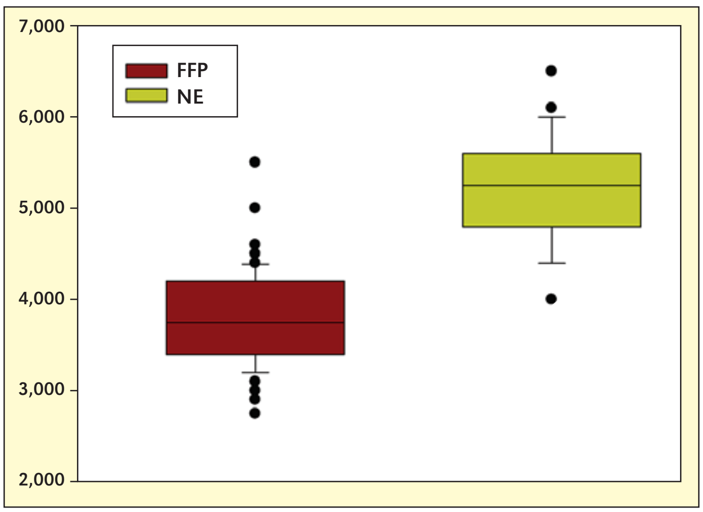


Figure 1. Yield variability in FFP and NE treatments in farmers' fields of Mewat. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

The yield variability in FFP treatments were higher than the NE-treated plots. NE estimates the attainable yield in a particular location based on historical data and through assessment of constraints such as drought, soil acidity, nutrient deficiency, or the existence of problem soils. Fertiliser recommendations from NE are based on this attainable yield assessment as well as estimation of cropping system nutrient balance for each field. Such algorithms generally produce recommendations that are aimed at achieving similar attainable yields for farmers within a pre-defined domain. This could be the reason for lesser yield variability in the NE treatments as compared to the FFP.

Average application of N, P_2O_5 and K_2O in farmers' fields were 117, 54 and 0 kg/ha, respectively. The average recommendation by NE was 122, 62 and 83 kg/ha of N, P_2O_5 and K_2O, respectively (**Figure 2**). The average N and P application

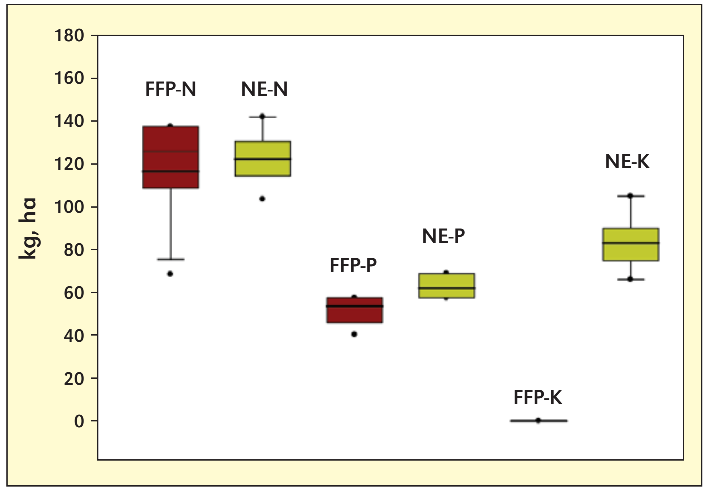


Figure 2. Comparison of N, P, and K application rates in FFP and NE. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median. The thicker line within the boxes represent the mean. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

rates were similar in FFP and NE, while farmers did not include K in their fertilisation schedule (**Table 1**). Cropping system nutrient balance is one of the major drivers of site-specific fertiliser recommendation.

Table 1. Agronomic and economic performance of Nutrient Expert® for wheat (NE) as compared to farmers' fertiliser practice (FFP) across all sites and years.

Parameter	FFP	NE	NE-FFP	
Grain yield, kg/ha	3,773	5,226	1,453	***
Fertiliser N, kg/ha	117	123	6	ns
Fertiliser P_2O_5, kg/ha	54	62	8	**
Fertiliser K_2O, kg/ha	0	83	83	***
Fertiliser cost, ₹/ha	4,911	10,190	5,279	***
GRF*, ₹/ha	53,566	70,813	17,247	***

*** and **: significant at <0.001 and 0.01 level; ns = not significant. Prices (₹/kg): wheat = 15.50; N = 16.90; P_2O_5 = 48.76; K_2O = 26.67; Zn = 152.00; S = 44.4; GRF = Gross Return over Fertiliser Cost.

NE, while estimating cropping system nutrient balance, assessed that farmers are not applying the required amount of K to their crops and recommended adequate amounts of K to wheat to reduce K mining from the soils. Comparing the nutrient application rates between the two treatments showed that the K application rates differ significantly between them (**Table 1**). It can be inferred that the yield advantage achieved through NE is mainly driven by higher K application rates.

Fertiliser cost increased significantly due to higher K application in the NE treatment as compared to FFP (**Table 1**). However, the gross return over fertiliser cost (GRF) in the NE treatment was significantly higher than the existing farmers' practice (₹17,247/ha) due to the additional wheat yield of nearly 1.5 t/ha. The results highlighted that field-specific fertiliser recommendation by the NE can substantially improve farmers' yield and profitability over their existing practices. This study also clearly indicated that adequate K application in wheat would be critical to improve yield and profitability of farmers. Adequate and balanced application of K would be particularly critical in water constrained areas like Mewat as adequate K within the plant reduces drought stress leading to less yield penalty under water stress conditions.

The partial factor productivity (PFP) of the applied nutrients (kg grain/kg applied nutrients) was estimated for all the farmers' fields for both the treatments (**Figure 3**). The average PFP under farmers' practice was 23 kg grain/kg applied nutrient, with a broad range of 14 to 54 kg grain/kg applied nutrient. For NE, the mean PFP was 20 kg grain/kg applied nutrient, and the range was 14 to 26 kg grain/kg applied nutrient. The lower average PFP in the NE plot was due to higher NPK application (267 kg/ha) as compared to FFP (171 kg/ha). The 96 kg/ha of extra NPK application, mainly driven by an average K_2O application of 83 kg/ha (**Figure 2**), produced 1,453 kg/ha of additional yield. However, due to climatic and water constraints the yield increment per unit of additional nutrient application was not high enough (15 kg grain/kg of extra NPK addition) to produce high overall PFP. However, the yield and economic advantage of the NE treatment were significantly higher than the FFP. The results highlighted an important point that improving nutrient use efficiency cannot be the singular goal of a nutrient management strategy, as inadequate application of nutrient will compromise yield and profitability. Rather, achieving higher yields and profitability with reasonably high PFP should be the goal of an improved nutrient management strategy that will be economically profitable and environmentally sustainable.

Side-by-side comparison of wheat grown under Nutrient Expert® (left) and Farmers' Fertilization Practice (right).

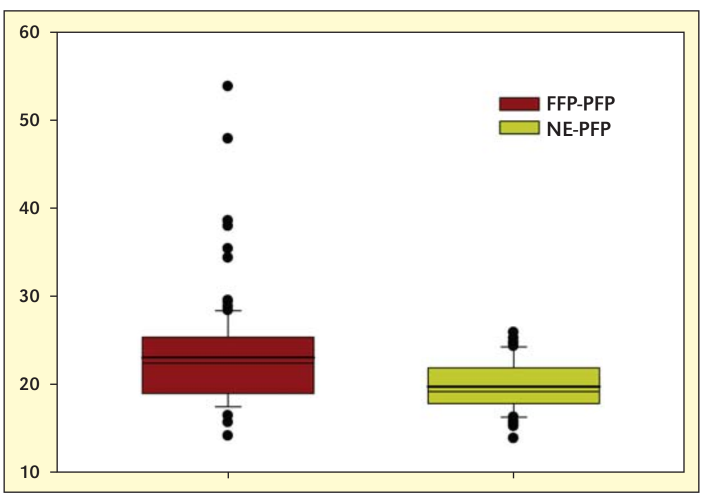


Figure 3. Partial factor productivity in FFP and NE treatments in farmers' fields. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median. The thicker line within the boxes represent the mean. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

The NE fertiliser decision support tool-based recommendation significantly improved wheat yield and farmer profitability in Mewat region of Haryana. The capacity of NE to develop a field-specific fertiliser recommendation without soil testing is a significant step towards providing science-based fertiliser recommendations to a large segment of smallholder farmers who do not have access to soil testing. The results showed that adequate and balanced application of K is critical for improving wheat yields in the water-stressed region of Mewat. Estimations in this study suggested that improving nutrient use efficiency cannot be a singular objective of improved nutrient management strategies, rather must be accompanied by higher yield and profitability for the farmers. BC-SA

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On-farm Performance of Nutrient Expert® for Maize: Fertiliser Recommendation, Yield, and Nutrient Use Efficiency

By Kaushik Majumdar, T. Satyanarayana, Sudarshan Dutta, Mirasol Pampolino, M.L. Jat, Vishal Shahi, Wasim Iftikar, Vidhi Govil, and V.K. Singh

On-farm trials over 500 sites across six maize growing states in India compared the Nutrient Expert® decision support tool-based fertiliser recommendation system against farmers' fertilisation practices and state recommended practices. Results showed significant yield improvement with higher nutrient use efficiency and savings of fertiliser through the tool-based recommendation.

Crop production in India increased radically since the green revolution in the early 1960s. Increased fertiliser use was one of the major drivers that changed the food security scenario in the country since then. The momentum, however, slowed in the past decade. Indian population is expected to be around 1.33 billion by 2020 (GOI, 2014), reaching 1.66 billion by 2050 (USCB, 2014). IFPRI (2012) summarised several studies that showed foodgrain demand in India reaching 293 million tonnes (M t) by 2020 and increasing to 335 M t by 2026. Estimates suggest that at the current level of production (263 M t), an additional 5 M t foodgrain has to be added each year to the national food basket for the next decade or so to feed the increasing population.

Maize, a crop of worldwide economic importance, provides approximately 30% of the food calories to more than 4.5 billion people in 94 developing countries (Jat et al., 2013). Maize is considered as the third most important food crop among the cereals in India and contributes to nearly 9% of the national food basket. Grown in an area of 8.55 M ha with an average productivity of 2.5 t/ha, maize contributes to more than half of the coarse cereal production of the country. The annual maize production in India is about 21.7 M t with an annual growth rate of 3 to 4 % (Jat et al., 2013). The rapid population growth, persistent poverty in areas where maize is a staple crop, rising price of main staples like rice and wheat, and increasing demand for maize as feed due to change in dietary preferences are driving the demand for maize (Majumdar, 2014) in India. Maize yields in India need to be increased significantly to sustain high growth rate to meet India's growing food, feed and industrial needs.

Imbalanced fertiliser application in crops is identified as one of the major reasons for decreasing crop response to fertiliser application and the consequent lower crop production growth rate in India. Despite the proven economic, social and environmental benefits of balanced fertilisation, its adoption at the farm level is low. The generally unbalanced use of fertiliser by farmers has raised concerns about achieving food security goals and also the environmental sustainability of such practice. The lack of appropriate tools and implementation mechanisms has been a major hindrance that restricted wide-scale adoption of balanced fertilisation.

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

The NE tool development in India was followed by a large-scale on-farm validation across different growing environments of maize. The NE-based recommendations were compared to the existing fertiliser recommendation practices such as farmers' fertilisation practices (FFP) and state recommendations (SR). The three treatments were implemented side-by-side in the same farmer's field where each plot size was ≥ 100 m². The current study reports on the pooled data from 510 on-farm trials in maize, spanning three seasons between 2011 and 2013. Since several cooperating Institutes were involved in the validation trials, all the treatments were not implemented in all locations. Besides, unforeseen events sometimes did not allow collection of data from all treatments and questionable data were not included from some trials. The exact number of data for each treatment is given in **Table 1**. The maize trials were done in Bihar, Odisha, Rajasthan, Andhra Pradesh, Karnataka, and Tamil Nadu.

As discussed earlier, the NE tool is based on the SSNM principles. SSNM advocates external application of nutrients to bridge the gap between indigenous soil nutrient supply and crop nutrient requirement for a target yield. In smallholder systems of India, farmers cultivate small pieces of land and management varies widely depending on awareness and resource availability. Such variable management decisions create large spatial and temporal variability in soil nutrient availability. Ideally the fertiliser management in such smallholder landscape should vary and be location-specific to avoid over- or under-use of nutrients. Farmers' fertilisation practices

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

Table 1. Modal values of fertiliser application rates, yield and partial factor productivity (PFP) in different treatments in maize validation trials.

Parameter	FFP (n=482)	SR (n=296)	NE (n=510)	NE-FFP	NE-SR
N, kg/ha	138 (27 to 550)	100 (80 to 280)	130 (90 to 257)	-8	30
P_2O_5, kg/ha	23 (0 to 280)	60 (22 to 75)	37 (17 to 92)	14	-23
K_2O, kg/ha	0 (0 to 352)	50 (0 to 75)	56 (18 to 143)	56	6
Yield, kg/ha	7,800 (1,024 to 11,766)	4,200 (1,051 to 10,785)	8,400 (2,337 to 12,460)	600	4,200
PFP, kg grain/kg nutrient	12.4 (7 to 78)	21 (6 to 46)	27.5 (10 to 62)	13.1	6.5

in India lack the necessary integration of information on soil nutrient supply and crop nutrient requirement. State fertiliser recommendations are generally based on response studies extrapolated to large areas and the spatial and temporal variability in soil nutrient supply between farms is not addressed adequately. In such a scenario, it is expected that there will be significant differences between the NE, SR and FFP fertiliser recommendations when a large dataset is compared. The expected outcome from the NE-based balanced and location-specific fertiliser recommendation could be several, including improved yield, higher nutrient use efficiency or saving of fertiliser and consequent improved economics of production and environmental stewardship of applied nutrients.

The comparative data of different treatments from the validation trials for maize are given in **Table 1**. We used the "MODE" values instead of "MEAN" to represent the dataset. The "MEAN" of large on-farm dataset often masks the general trend of the data. On the other hand, "MODE" represents the central tendency of the dataset that is a more realistic representation and easier to explain.

The NE-based fertiliser recommendation for maize improved yield as compared to FFP and SR (**Figure 1**) across multiple locations in India. The NE recommendation produced the highest modal yield (8,400 kg/ha) followed by FFP (7,800 kg/ha) and SR (4,200 kg/ha) (**Table 1**). Other studies using NE showed significant yield, economic and environmental advantage from the tool-based fertiliser recommendation as compared to existing practices (Satyanarayana et al., 2012; Sapkota et al., 2014).

The nutrient use in FFP highlighted the generally imbalanced practices adopted by farmers. The N, P_2O_5 and K_2O application rates varied widely, 27 to 550, 0 to 280 and 0 to 352 kg/ha, respectively (**Table 1**). The modal N, P_2O_5 and K_2O application rates were 138, 23 and 0 kg/ha, respectively, which outlined the lack of K application by farmers even in a crop like maize that removes large amount of K from a field. The lack of K application has been flagged earlier as one of the main reasons for decline in maize yield in major production zones of Bangladesh (Timsina et al., 2013). Some locations showed abnormally high applications rates such as more than 500 kg/ha of N, 250 kg/ha of P_2O_5 and 300 kg/ha of K_2O that may indicate over-use of fertiliser. Maize yield in the FFP was reasonably high (7,800 kg/ha) but the low (12.4 kg grain/kg nutrient) partial factor productivity (PFP) suggested inefficient management of nutrients by farmers (**Table 1**).

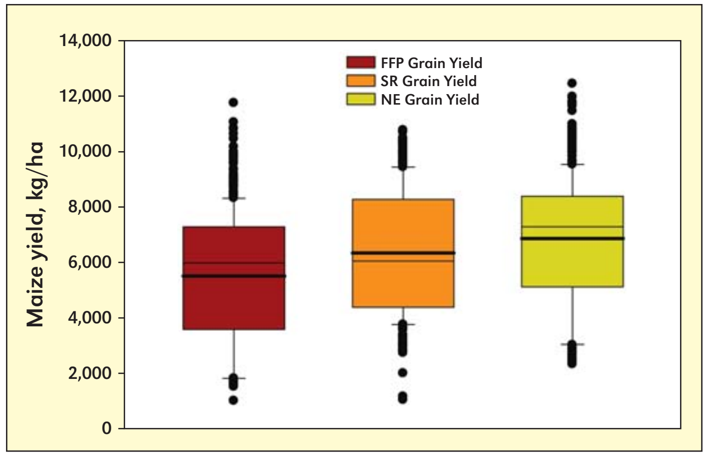

Figure 1. Average maize grain yield in Nutrient Expert® validation trials (n=510) in India. Boxes represent data within the first and third quartiles (interquartile range). The thin line denotes the second quartile or median. Lines extending beyond the interquartile range denote the 10th to 90th percentile of the data. Statistical outliers are plotted as individual points outside these lines.

Earlier studies (Satyanarayana et al., 2012) have suggested that fertiliser recommendations developed for open pollinated varieties (OPV) are being used for hybrid maize varieties as well. Hybrid maize has far higher yield potential than OPVs and would require higher quantities of plant nutrients for proper expression of yield. The experimental data (**Table 1**) showed modal value of N, P_2O_5 and K_2O application at 100, 60 and 50 kg/ha, respectively for the SR treatment that produced the lowest modal yield of 4,200 kg/ha among the treatments. The NE validation trials solely used hybrid varieties and apparently the state recommended fertiliser rates were inadequate to achieve high yields. Maize is rapidly replacing other traditional crops in several areas in India and farmers are increasingly adopting hybrid varieties. The absence of appropriate fertiliser recommendations for hybrid maize for different ecology and seasons are prompting farmers to adopt unscientific fertiliser application strategies that may affect sustainability of maize production systems.

The NE-based fertiliser recommendation produced the

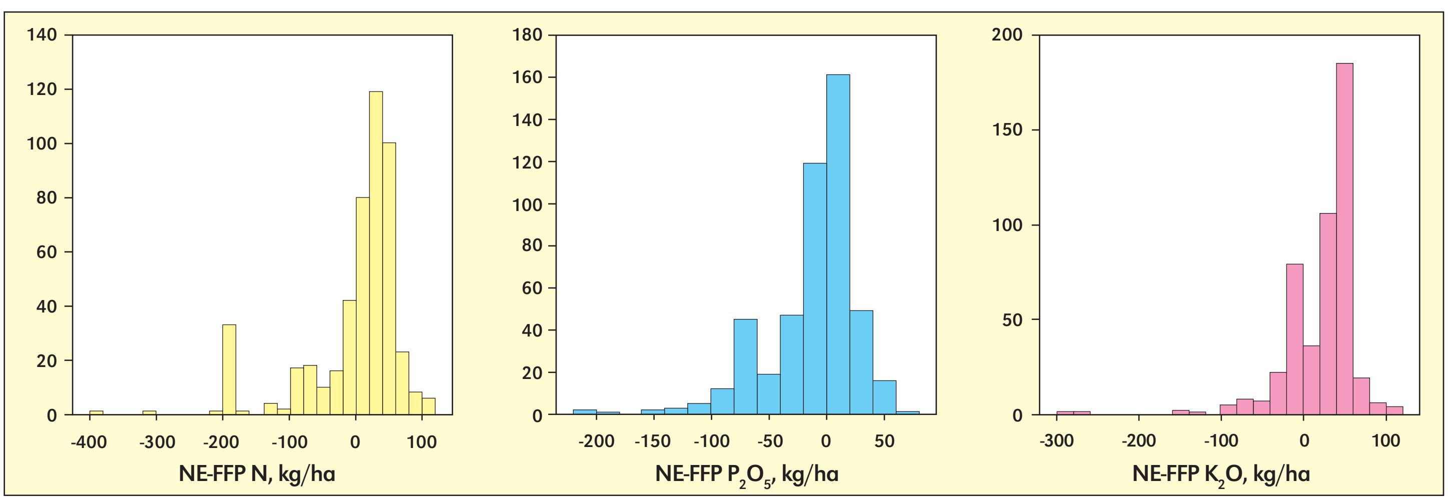

Figure 2. Frequency distribution diagrams of the difference between N, P and K application rates in NE and FFP.

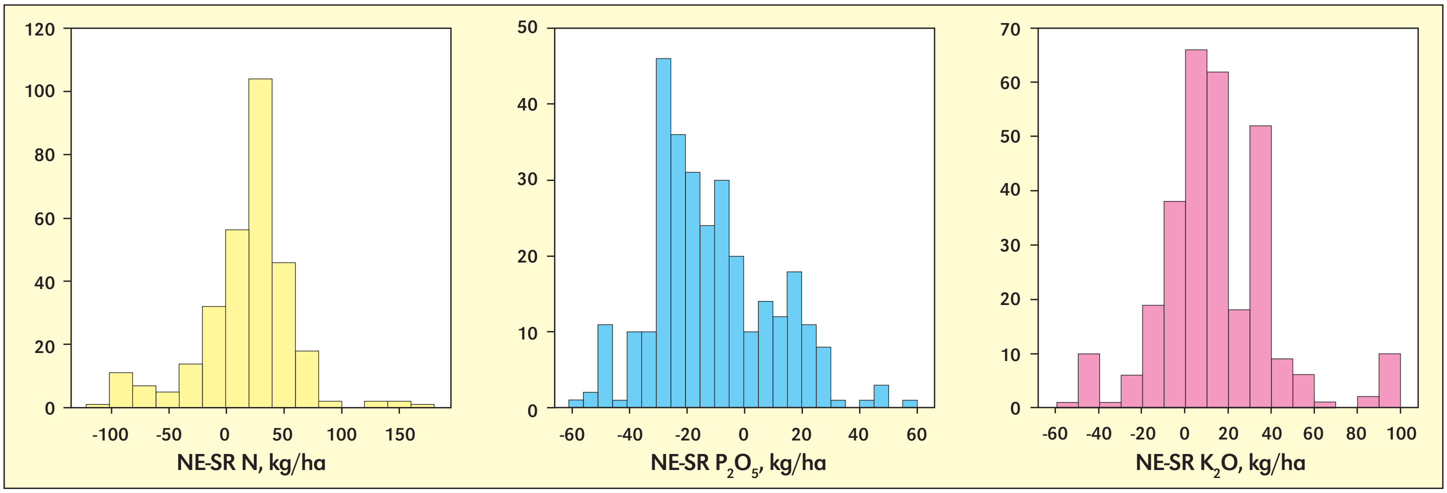

Figure 3. Frequency distribution diagrams of the difference between N, P and K application rates in NE and SR.

highest maize yield (8,400 kg/ha) among the three treatments (**Figure 1, Table 1**). This has been achieved at a PFP of 27.5 kg grain/kg nutrient, the highest among the three treatments. The NE recommendations for individual farm fields were developed using information on attainable yield, cropping system nutrient balance based on nutrient input and off-take from the field, previous crop history, local constraints etc. that allowed optimisation of nutrient application rates. This ensured high yield and high nutrient use efficiency and may provide an opportunity to sustainably intensify maize production systems around the country.

We used the frequency distribution diagrams to bring more clarity on the difference between nutrient application rates among the treatments. The differences in N, P_2O_5 and K_2O application rates (kg/ha) between the 'NE and FFP' (**Figure 2**) and 'NE and SR' (**Figure 3**) were plotted as frequency distribution diagrams. The figures reveal that NE recommendations for N, P and K are lower than SR or FFP application rates in a large number of trials.

Analysis of the data revealed that of the 484 on-farm trials that compared the NE recommendations with the FFP, N, P_2O_5 and K_2O recommendations by NE were lower than FFP in 146 (30%), 254 (52%) and 124 (26%) cases, respectively. The difference in NE-FFP rates ranged from (-) 400 to (+) 113 kg/ha for N, (-) 209 to (+) 60 kg/ha for P_2O_5 and (-) 297 to (+) 113 kg/ha for K_2O.

Similarly, 301 on-farm trials compared the NE recommendations with the SR, and N, P_2O_5 and K_2O recommendations by NE were lower than SR in 69 (23%), 221 (74%) and 74 (25%) cases, respectively. The difference in NE and SR rates ranged from (-) 110 to (+) 170 kg/ha for N, (-) 58 to (+) 57 kg/ha for P_2O_5 and (-) 53 to (+) 93 kg/ha for K_2O. The range of differences between NE and FFP are wider than NE and SR, suggesting more imbalances in fertiliser application by farmers.

The wide range of difference seen above between NE recommended, and FFP and SR rates probably arises from the fact that NE developed fertiliser application rates for individual farm fields are based on an estimated attainable yield and the nutrient balance in cropping systems followed by the farmer. An objective assessment of nutrient input from crop residues, organic manure, irrigation water, and residual fertility from the application of nutrients in the previous crop helped improved estimation of fertiliser rates by the NE tool. A recent study (Singh et al., 2014) also showed significant improvement in yield, profitability and nutrient use efficiency when farm-specific fertiliser recommendations were developed based on reciprocal internal efficiency of the crop (i.e., kg nutrient uptake in above-ground plant dry matter per t grain produced) and nutrient inputs through external sources other than fertilisers.

The current study showed that location-specific fertiliser recommendation from the NE tool significantly improved maize yield and nutrient use efficiency over farmers' practice and state recommendations across a wide range of growing environments in India. The comparative analysis revealed that fertiliser application in maize based on NE provides significant opportunity for saving fertiliser, which may improve farm profitability and environment stewardship of applied nutrients. BC-SA

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IPNI South Asia Program Holds Research Cooperators' Meet at the University of Agricultural Sciences, Dharwad, Karnataka

IPNI, a global Not-for-Profit Research & Education Organisation, is currently active in 50 countries around the world. IPNI research programs are working to help define the basis for appropriate use and management of plant nutrients, especially focusing on the environmental and economic issues related to their use. In India, IPNI works closely with ICAR Institutes, State Agricultural Universities and CGIAR Organisations to combine sound agronomy and fertiliser best management practices to improve crop productivity and farmer profitability in an environmentally sustainable manner.

IPNI Research Cooperators' Meet, a biennial event, brings together researchers of the NARES and CG Organisations who are collaborating with IPNI to define appropriate nutrient management strategies for important crops and cropping systems of the region. Padma Bhushan Dr. R.S. Paroda, Hon'ble Chairman, Haryana Kisan Ayog, formerly Director General ICAR and Secretary DARE, inaugurated the 2014 Research Cooperators' Meet of IPNI.

Nearly 300 delegates, spanning more than 25 organisations, attended the two-day meeting. Among the notable participants, besides the researchers, were Dr. J.V. Goud, Founder Vice Chancellor, UAS, Dharwad, Dr. R.R. Hanchinal, Chairman, PPV & FRA, New Delhi, Dr. D.P. Biradar, Vice Chancellor, UAS, Dharwad, Dr. Dipak Sarkar, Former Director, NBSS & LUP (ICAR), Dr. Indu Sharma, Director, DWR (ICAR), Dr. B. Gangwar, Director, PDFSR (ICAR), Dr. A.K. Singh, Director, ZPD Zone II (ICAR), Dr. M.L. Jat, Senior Cropping System Agronomist (CIMMYT) and Coordinator of CCAFS, and Dr. Adrian M. Johnston, Vice President and Asia & Africa Coordinator, IPNI.

Padma Bhushan Dr. R.S. Paroda, Hon'ble Chairman, Haryana Kisan Ayog, and Trust for Advancement Agricultural Sciences (TAAS) in his inaugural address as Chief Guest of the program stressed upon the need for renewed focus on management aspects of agricultural production systems, particularly nutrient management, to achieve food and nutritional security goals of the region. He suggested that appropriate nutrient management strategies need to be developed and adopted to accrue the full benefit from the improved genetic material (seeds) now available in the region. Dr. Paroda said, "the disparity between the nutrient application in crops and nutrient off-take with harvested products and crop residues from agricultural fields is a matter of great concern. This is promoting nutrient mining from soils, adversely affecting crop productivity, farmer profitability and soil health; and may jeopardise future food security goals of the South Asian countries." He suggested sustainable ecological intensification of agricultural production systems through precise use of resources such as land, water and nutrients as a roadmap for the region. Dr. Paroda expressed his satisfaction that a large group of eminent scientists from the NARES and CG Institutes are involved with IPNI to develop precision nutrient management strategies for the smallholder systems of South Asia.

The participating scientists at the IPNI Research Cooperators' Meet 2014 presented research results from collaborative research with IPNI and a road map for developing scalable solutions to implement nutrient best management practices in the region were discussed. BC-SA

IPNI Highlights Excellence During Awards Ceremony at 2014 Research Cooperators' Meeting

A biography for each Award recipients is provided below.

Dr. A.K. Srivastava, National Research Center for Citrus, Nagpur, Maharashtra – Dr. A.K. Srivastava received his M.Sc. (Ag) and Ph.D in Soil Science from the Banaras Hindu University in 1984 and 1988, respectively. Dr. Srivastava is Principal Scientist (Soil Science) at Indian Council of Agricultural Research - National Research Centre for Citrus, Nagpur. He has been extensively working on different aspects of citrus nutrient management over the last 25 years. His specific areas of research interest are soil-plant nutrient diagnostics, site specific nutrient management, microbiology of citrus rhizosphere, soil carbon loading and microbial turnover of nutrients, fertigation scheduling through partitioning of nutrients and water vis-à-vis crop phenology, and nutrient mapping using geospatial tools.

He is credited with 92 Research Papers and 30 Policy Review Papers in International and National Journals. Dr. Srivastava received the S. N. Ranade Award for Excellence in Micronutrient Research, FAI Silver Jubilee Award, and the International Plant Nutrition Institute-FAI Award. He has authored a book Citrus: Soil and Climate, Citrus Nutrition published by IBDC, Lucknow, and is the Editor of a book entitled Advances in Citrus Nutrition by Springer-Verlag, The Netherlands. He is a member of Editorial Boards of the Journal of Plant Nutrition, Communications in Soil Science and Plant Analysis, and is an Associate Editor of the Agronomy Journal. He is the fellow of 9 professional academic societies including Indian Society of Soil Science. Dr. Srivastava has been a collaborator of IPNI for over 15 years.

Dr. B.S. Dwivedi, Indian Agricultural Research Institute, New Delhi – Dr. B.S. Dwivedi did his M.Sc. and Ph.D. in Soil Science and Agricultural Chemistry from CS Azad University of Agriculture & Technology, Kanpur. He was a brilliant student, who secured first position in U.P. Board during SSC Examination, and then in the University during his graduation. After joining Agricultural Research Service of the ICAR, he served at ICAR Res. Complex for NEH Region, Shillong (now at Barapani), PDFSR, Modipuram, and IARI, New Delhi. At present, he is the Head, Division of Soil Science and Agri. Chemistry, Indian Agricultural Research Institute.

During his professional career of over 28 years, Dr. Dwivedi made original research contributions in the area of soil fertility and nutrient management in intensive cropping systems. Important areas of his research interest are: restoration and improvement of soil health under rice-wheat system, site-specific nutrient management, conservation agriculture, and soil testing. Dr. Dwivedi has been associated with IPNI for over 15 years through several research and extension programs. Dr. Dwivedi's outstanding contributions have been recognised through NAAS Fellowship, Dr. J.S.P. Yadav Memorial Award for Excellence in Soil Science, IPNI-FAI Award (2004 and 2014), and TSI-FAI Award (1989). He is Chief Editor of the Journal of the Indian Society of Soil Science.

Dr. D.P. Biradar, University of Agricultural Sciences, Dharwad, Karnataka – Dr. D. P. Biradar is the Vice Chancellor of the University of Agricultural Sciences (UAS), Dharwad, Karnataka. Dr. Biradar did his B.Sc. (Ag.) and M.Sc. (Ag) at the UAS, Dharwad, Karnataka, and received his Ph.D. at the University of Illinois at Urbana-Champaign, USA, in 1993. Dr. Biradar's areas of research interest are transgenic crops, molecular diversity of plant species, farming systems research and site specific nutrient management of important crops of Northern Karnataka. Dr. Biradar is closely associated with IPNI for more than 15 years and has contributed significantly in the development and dissemination of site specific nutrient management in rice, wheat, maize, sugarcane and cotton. Dr. Biradar is associated with the IPNI Global Maize Project and development and dissemination of the Nutrient Expert® Decision Support Tool for rice, wheat and maize. Dr. Biradar's contribution was recognised though several awards, including the Sir C. V. Raman Award for Young Scientist (2002); Dr. A.P.J. Abdul Kalam National Award (2008); Konda Laxman Bapuji Award (2008). Dr. Biradar is Fellow of the National Environmental Science Academy (2005); International Benevolent Research Forum (2007); and the National Academy of Biological Sciences (2007).

Dr. M.L. Jat, International Maize and Wheat Improvement Center (CIMMYT), New Delhi – Dr. M.L. Jat obtained his B. Sc. (Ag) and M. Sc (Ag) from Rajasthan Agricultural University, and his Ph. D. from the Indian Agricultural Research Institute (IARI), New Delhi. He is currently the Senior Cropping Systems Agronomist & CIMMYT-CCAFS South Asia Coordinator, Global Conservation Agriculture Program of International Maize and Wheat Improvement Centre (CIMMYT). Dr. Jat contributed to the development and deployment of Conservation Agriculture and precision agriculture based management technologies, climate resilient practices and capacity development to several thousand farmers and stakeholders in South Asia. He has published over 200 peer-reviewed journal articles (including a recent paper in NATURE CLIMATE CHANGE), book chapters, bulletins, reviews, symposia proceedings & abstracts. An Associate Fellow of the National Academy of Agricultural Sciences (NAAS), and Fellow of the Indian Society of Agronomy (ISA), he has received the IPNI-FAI award for Best Research on Management and balanced use of inputs in achieving maximum yield and several other recognitions. Dr Jat has been associated closely with IPNI for development, validation and dissemination of Nutrient Expert® decision support tools for rice, wheat and maize.

Dr. Rakesh Kumar, Birsa Agricultural University, Ranchi, Jharkhand – Dr. Rakesh Kumar, is currently Professor of Soil Science and Agricultural Chemistry at the Faculty of Agriculture, Birsa Agricultural University, Ranchi, Jharkhand. Dr. Kumar received his B. Sc (Ag), M. Sc. (Ag) and Ph. D. from the Birsa Agricultural University, Ranchi, Jharkhand. Dr. Kumar has been involved with IPNI in plant nutrition research and extension activities in Jharkhand for more than 15 years and is Principal Investigator for the IPNI Global Maize research project at Ranchi. He has contributed significantly to the development and dissemination of the maize and wheat Nutrient Expert® in Jharkhand through farmer participatory activities. Dr. Kumar's other research interests include assessment of nutrient and pollutant status in Jharkhand soils, nutrient management in acid soils and improved management of agro-forestry in Jharkhand. Dr. Kumar has more than 30 research publications in reputed journals.

Dr. Sushanta Kumar Pattanayak, Orissa University of Agriculture & Technology, Bhubaneswar, Odisha – Dr. Sushanta Kumar Pattanayak is currently Professor at the Department of Soil Science & Agricultural Chemistry, Orissa University of Agriculture & Technology, Odisha. Dr. Pattanayak received his doctoral degree from the Indian Agricultual Research Institute, New Delhi, in 1991. Dr. Pattanayak's research interest is in soil fertility, fertiliser and bio-fertiliser use in crops, and site-specific nutrient management in crops and cropping systems in the acid soils of Odisha. Dr. Pattanayak, through his research and extension work in soil fertility management, has made significant contribution in the lives of tribal communities in resource poor areas of Odisha. His work has improved crop yields and economics of production and improved the livelihood of farmers in smallholder systems. Dr. Pattanayak has been associated with IPNI for over 15 years and has published more then fifty research and extension publications in the national and international journals. Dr. Pattanayak is a key partner of IPNI in the development and dissemination of the fertiliser dicision support tools for rice and maize in Odisha.

Dr. Vinay Singh, R.B.S. College, Agra, Uttar Pradesh – Dr Vinay Singh was born in Tajpur, Mathura (U.P.) on 10 July 1945 in a farmer's family. He completed his graduation in 1965, acquired Doctorate in 1978 and Post doctorate in 1991 from Agra University, Agra. He started his professional career in J.V. College Baraut, (Meerut) and later joined B.R College (now known as R.B.S. College) Agra in September, 1970. He continued on various positions in this college till his superannuation in June, 2008. He guided research work of number of post graduate and doctoral students. He had over 250 publications to his credit including several books, technical bulletins and research articles published in national and international journals of repute. He is recipient of several awards including TSI - FAI Award in 1994 for outstanding research on Sulphur, S.N. Ranade Memorial Award in 2000 for excellence in micronutrients research and FAI Award for best publication. He has contributed significantly in the field of soil fertility and plant nutrition and has been a long-term cooperator of IPNI in several research projects. Dr. Singh has made significant contributions in the development and dissemination of Nutrient Expert® decision support tool in Uttar Pradesh.

Dr. V.K. Singh, ICAR-Indian Institute of Farming Systems Research, Modipuram, Uttar Pradesh – Dr. V.K. Singh obtained his Ph D from GBPUAT, Pantanagar in 1999. Dr. Singh is currently ICAR National Fellow and Principal Scientist at ICAR-Indian Institute of Farming Systems Research, Modipuram, India, and has made significant contributions in developing site-specific nutrient management strategies for crops and cropping systems, and using GIS for soil fertility and resource utilisation mapping to ensure precision in fertiliser recommendation in India. Extensive on-station and on-farm studies conducted by him helped in the development of improved nutrient management strategies for cereal-based cropping systems for improving crop productivity and for enhancing nutrient use efficiency. Adoption of his findings through extensive educational activities helped the farmers in improving soil health and productivity of important cropping systems of the Indo-Gangetic Plains. Dr. Singh has been a cooperator of IPNI for over 10 years and has significantly contributed to the dissemination of improved nutrient management practices among Indian farmers. Dr. Singh is a significant partner in the development of the cropping system based Nutrient Expert® fertiliser decision support tool in India.

Dr. Y.R. Aladakatti, University of Agricultural Sciences, Dharwad, Karnataka – Dr. Y.R. Aladakatti is currently Professor and Principal Scientist (Agronomy) at All India Coordinated Cotton Improvement Project, Agricultural Research Station, University of Agricultural Sciences (UAS), Dharwad. Dr. Aladakatti received his B. Sc. (Ag) at UAS, Dharwad, M. Sc. (Ag) at UAS, Bangalore and Ph. D. in Agronomy at UAS, Dharwad. He has served in the Department of Agriculture, Govt. of Karnataka, for 13 years before joining as an Assistant Professor at the UAS, Dharwad. Dr. Aladakatti has done significant research in water management of crops and cropping sequences and contributed to the development of irrigation strategies for major field and horticultural crops in Northern Karnataka. He has been associated with IPNI in the development of site-specific nutrient management strategies for transgenic cotton. He is the Principal Investigator of the IPNI Global Maize Project at Dharwad. Dr. Aladakatti is also involved in the IPNI effort to develop and disseminate fertiliser decision support tools for rice, wheat, maize, cotton and soybean. He has contributed over 90 scientific publications in national and international journals. Dr. Aladakatti is also closely involved in the transfer of agro-technologies and their impact assessment amongst the farming community through field demonstrations, field days, trainings, field visits, radio and TV talks and technical bulletins.

Nutrient Expert® – Going Global with Improved Fertiliser Recommendations

By Adrian M. Johnston

Addressing the challenge of making science-based fertiliser recommendations to smallholder farmers throughout Asia and Africa has been a key focus of IPNI staff over the decades. As students of agriculture we all learned about soil testing methods, correlation and interpretation as the key step in this process. However, this entire approach has not been successful on smallholder farms due to access, cost or inadequate timeliness in delivery of results. As a result, some alternative had to be found to address this problem for smallholder farmers in Asia and Africa.

The development of the decision support software, Nutrient Expert®, by IPNI staff came about to address the growing need for science-based fertiliser recommendations for smallholder farmers in Asia and Africa. After almost 8 years of development, verification and application of the software, we have grown in both confidence and understanding of how successful this tool will be in helping meet the needs of small farmers. With software now available for downloading from the web (http://software.ipni.net) IPNI is providing a free of charge option for making nutrient recommendations for wheat and maize production in Asia. A rice tool is currently under pre-release large-scale validation phase in Asia. A maize tool for sub-Saharan Africa is close to release, and a wheat tool for North Africa is in development, as are soybean tools for Asia and a cotton tool in South Asia. Work has just recently started to develop a tool for cassava in SE Asia and central Africa.

In the course of research and extension program development in IPNI, one of the key questions always being asked is can this technology or practice be taken to scale? Where might it be applicable within other agricultural systems and IPNI regions of the world? With the success of the Nutrient Expert® program, getting other staff and programs of IPNI interested in adapting the tool to their regions was relatively easy—success was our best selling tool. However, how would such a tool be moved to a more open, public scale allowing the access and use by others?

Having the Nutrient Expert® tools available for downloading from the web is one way of providing open access to all interested stakeholders. Currently we are developing versions that use databases on the web, allowing the tool to be run as a web-based version and enabling easy updating of the available tools. We are also investigating the options for moving the Nutrient Expert® tool to an ICT platform, where agriculture extension and industry workers would be able to access and use the software with a tablet in the farmers field. All of these improvements are being developed in cooperation with the IT industry, where the expertise to succeed in delivery of the technology exists. Finally, IPNI also has to decide when, and if, they are going to release the programming code for Nutrient Expert® to the public. As with all crop production support models, it is likely an improved version is out there once our current technology gets into the hands of others with additional ideas to pursue the continuous improvement we would like to see. BC-SA

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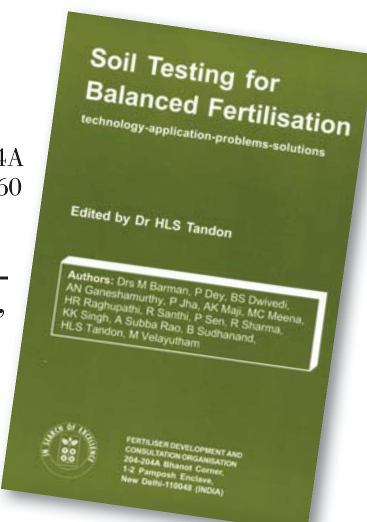
New Book on Soil Testing for Balanced Fertilisation: Technology-Application-Problems-Solutions



Edited by Dr. H.L.S. Tandon.

ISBN: 81-85116-69-5. Pp. 170+xiv Fertiliser Development and Consultation Organisation, 204-204A Bhanot Corner, Pamposh Enclave, New Delhi 110048 (India). Price in India ₹600. Outside India US$60 (inclusive of airmail dispatch). Contact tandonhls@gmail.com

This book is devoted to soil testing as a research-based tool for making fertiliser recommendations and its various aspects ranging from various technologies, their application, problems and possible solutions. The nine chapters deal with subjects ranging from (i) various methodologies for developing soil test-based fertiliser recommendations from conventional approaches to GIS-based tools, (ii) the agro-economical evaluation of soil test based fertiliser recommendations, (iii) special features of soil testing in coordination with plant analysis for horticultural tree crop, (iv) initiatives required for rejuvenating soil testing services, (v) government initiatives and programmes for expanding and strengthening soil testing services, (vi) field level experiences, problems and solutions for making soil testing a more widely usable facility as outlines by a state government and a fertiliser company involved in soil testing for many years, and finally, (vi) an introduction to the various analytical instruments being used or for potential use in modern well equipped, appropriately staffed soil testing laboratories. These topics have been covered by experts drawn from ICAR institutes, agricultural universities, government departments, and the fertiliser industry.

This book is intended for use by a diverse readership who are interested in the optimum, balanced and efficient use of plant nutrients through fertilisers for crop production and maintenance of soil health. Its target readership are persons, organisations or entrpreneurs operating or setting up new soil testing labs. It is also meant for agronomy/farm advisory personnel of the fertiliser industry, students, teachers, researchers in colleges, agriculture/horticultural universities; research stations, ICAR institutes, projects and research centers as well as independent/private institutions. Other potential readers could be officers of the state departments of agriculture/horticulture, rural development training centers, cane managers of sugar mills, plantation managers, and agricultural consultants.

Active Research within the IPNI South Asia Region

Below is a listing of the current research that is being conducted throughout the IPNI South Asia Region. More details on these projects can be obtained from IPNI Staff, or on-line at: http://research.ipni.net

Global Maize Project in India: Ranchi, Jharkhand – Site-Specific Nutrient Management in Maize-Wheat Cropping System in Ranchi, Jharkhand
Project Leader: Dr. Rakesh Kumar Saxena, Birsa Agricultural University, Department of Soil Science and Agricultural Chemistry, Ranchi, Jharkhand; e-mail: rkssacbau@gmail.com - Project#IPNI-2009-IND-GM22

Global Maize Project in India: Dharwad, Karnataka – Site-Specific Nutrient Management in Maize-Wheat Cropping System in Northern Karnataka
Project Leader: Dr. Y.R. Aladakatti, Principal Scientist, All India Coordinated Cotton Improvement Project (AICCIP), Agril. Research Station, Dharwad Farm, University of Agricultural Sciences, Dharwad; e-mail: yraladakatti@rediffmail.com - Project#IPNI-2009-IND-GM35

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

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

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

Site-Specific Nutrient Management for the Rice-Maize System in Bihar
Project Leader: Dr. M.L. Jat, CIMMYT, New Delhi, India; e-mail: m.jat@cgiar.org - Project#IPNI-2010-IND-509

Comparative Evaluation of Nutrient Dynamics under Conventional and No-till Systems of Crop Establishment in Rice-Wheat and Rice-Maize Cropping Systems
Project Leader: Dr. B.S. Dwivedi, Indian Agricultural Research Institute, Soil Science, New Delhi, India; e-mail:bsdwivedi@rediffmail.com - Project#IPNI-2010-IND-517

Fertility Mapping and Balanced Fertilisation for Sustaining Higher Productivity of the Pearl Millet-Wheat Cropping System in Agra District
Project Leader: Dr. Vinay Singh, Raja Balwant Singh College, Agra University, Department of Agricultural Chemistry & Soil Science, Agra, Uttar Pradesh; e-mail: apsr_1999@yahoo.co.in - Project#IPNI-2010-IND-506

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

Balanced Fertilization for Enhancing the Productivity of the Pearl Millet-Wheat-Green Gram Crop Sequence in Agra, Uttar Pradesh
Project Leader: Dr. Vinay Singh, R.B.S. College Bichpuri, Agra, Department of Agricultural Chemistry and Soil Science, Agra, Uttar Pradesh; e-mail: apsr_1999@yahoo.co.in - Project#IPNI-2012-IND-519

Climate Change Mitigation and Adaptation through Conservation Agriculture and Precise Nutrient Management in Current and Future Cereal-based Cropping Systems of the Indo Gangetic Plains
Project Leader: Dr. Yashpal Singh Saharawat, Indian Agricultural Research Institute, Soil Science Indian Agricultural Research Institute, New Delhi, India; e-mail: y.saharawat@cgiar.org - Project#IPNI-2013-IND-520

Assessment of Agronomic and Economic Benefits of Fertiliser Use in Maize Production Systems under Variable Farm Size, Climate and Soil Fertility Conditions in Eastern India
Project Leader: Dr. Kaushik Majumdar, International Plant Nutrition Institute (IPNI), Gurgaon, Haryana; e-mail: kmajumdar@ipni.net - Project#IPNI-2012-IND-521

Nutrient Optimization and Yield Intensification of Major Cereal Systems of Eastern India
Project Leader: Dr. Mahua Banerjee, Visva Bharati University, Department of Agronomy, Soil Science, Agril. Engineering, Plant Physiology, Animal Sciences (ASEPAN), Birbhum, West Bengal; e-mail: mbanerjee16@rediffmail.com - Project#IPNI-2013-IND-522

Assessing the Contribution of Nutrients to Yield of Hybrid Rice and Maize through Omission Plot Techniques in Bihar
Project Leaders: Dr. Shiveshwar Singh, Rajendra Agricultural University, Pusa, Bihar, Department of Soil Science; e-mail: sp26814@gmail.com; S.P. Singh, Department of Soil Science, Rajendra Agricultural University, Pusa, Samastipur, Bihar; e-mail: sp26814@gmail.com - Project#IPNI-2013-IND-523

Assessment of Nutrient Contribution towards Yield of Bt Cotton through Omission Plot Techniques in Karnataka
Project Leader: Dr. Y.R. Aladakatti, University of Agricultural Sciences, Department of Agronomy, Agricultural Research Station, Karnataka, India; e-mail: yraladakatti@rediffmail.com - Project#IPNI-2013-IND-524

Evaluating Principles of 4R Nutrient Stewardship in the Rice-Maize-Greengram Cropping System for Improved Productivity and Profitability of Farmers in Odisha
Project Leader: Dr. Sushanta Kumar Pattanayak, Orissa University of Agriculture and Technology, Soil Science and Agricultural Chemistry, Odisha, India; e-mail: sushanta_1959@yahoo.com - Project#IPNI-2014-IND-525

Indigenous Nutrient Supplying Capacity of Vertisols under Cotton and Soybean
Project Leader: Dr. V.K. Kharche, Panjabrao Deshmukh Krishi Vidyapeeth, Department of Soil Science and Agricultural Chemistry. Maharashtra, India; e-mail: vilaskharche@rediffmail.com - Project#IPNI-2013-IND-526

Assessment of Agronomic and Economic Benefits of Fertiliser Use in Maize Production Systems under Variable Farm Size, Climate and Soil Fertility Conditions in Odisha
Project Leader: Dr. Sushanta Kumar Pattanayak, Orissa University of Agriculture and Technology, Soil Science and Agricultural Chemistry, Odisha, India; e-mail: sushanta_1959@yahoo.com - Project#IPNI-2013-IND-527

Transfer, Evaluation and Dissemination of an Innovative Fertiliser Management Tool Nutrient Expert® for Increasing Crop Yields and Farmers' Income in Eastern Nepal
Project Leader: Dr. Netra Pratap Sen, Executive Director, Forward Nepal; e-mail: netrapsen@wlink.com.np - Project#IPNI-2014-NPL-1

IPNI South Asia Program 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).

Nutrient Expert®— A Success Story for Smallholder Farmers in South Asia

Striking a balance remains the focus of IPNI research programs in nutrient management. In particular balancing nutrient application to optimize yield, quality, economic return and minimize environmental impact. However, our work around the world provides us with so many examples of how challenging this task has become. Whether it is access to nutrients, cost of products, distortions related to subsidies in countries, or simple lack of knowledge, many farmers remain at a significant disadvantage when it comes to using nutrient management to improve their agricultural production.

Making a science-based fertiliser recommendation continues to be our priority. In most regions of the world we develop fertiliser recommendations using soil analysis as our principle field assessment tool. While this remains the basis of most recommendations in South Asia, the lack of access to soil testing, or cost, mean that few farmers actually use soil testing. Rather most have to rely on suggestions from neighbors, fertiliser dealers, or their financial resources when it comes to determining fertiliser application rates. If we are going to achieve our objective of providing site-specific nutrient management (SSNM) to smallholder farmers in South Asia this approach is unacceptable.

Nutrient Expert® (NE) is a new option to help solve the challenge of smallholder access to science-based fertiliser recommendations. In fact, NE is capable of providing both a SSNM recommendation as well as providing fertiliser source, rate and timing guidance to optimize crop response. Developed using on-farm data collected in the agro-ecological regions of South Asia, NE is proving to be a powerful decision support tool, which can be easily placed in the hands of advisors to farmers, and in some cases computer-trained farmers. Developed to provide fertiliser recommendations in the absence of soil testing, the NE tool is also able to use soil test data if available for a specific field. The recommendation generated is tailored to the farmers own yield goal, field management history and prevailing environmental conditions. Recommendations can be manipulated in-season based on the rainfall patterns, avoiding overuse of nutrients when rainfed agriculture suffers drought. Finally the NE model provides an economic analysis to help the farmers make decisions on their fertiliser management options related to expected returns. Together, these options in the NE tool have changed the ability of farmer advisors to meet the SSNM recommendations of smallholder farmers.

Proof of concept remains critical to widespread adoption. That is the approach we have adopted in IPNI with NE. We have spent several years conducting rigorous verification field trials with our cooperators across South Asia to ensure the NE tool is up to meeting the needs of local farmers. This issue of Better Crops South Asia provides the detailed information on how NE was developed in the region, and the results of the model verification with wheat and maize. We are confident that readers will find this information of great interest and cause for reconsidering our options when it comes to making SSNM recommendations to smallholder farmers.

Future options – where to next? Our work with NE to date has been very encouraging and motivating to both IPNI staff and our collaborators. Like all new research approaches, we started slow with the key crops wheat and maize. We are currently working to develop NE models that will support rice, soybean and cotton at this time. We are motivated in our efforts based on our current success, and look forward to future opportunities to work on new crops, and in new regions of South Asia.

Adrian Johnston
IPNI Vice President, Asia & Africa Group

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