Development and Evaluation of Nutrient Expert for Wheat in South Asia

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Nutrient Expert (NE) for Wheat, a new nutrient decision support tool, is based on the principles of site-specific nutrient management (SSNM) and recommends balanced application of nutrients based on crop requirement. The tool was a joint development of wheat stakeholders in India including representatives from national research and extension system, private industries, International Maize and Wheat Improvement Center (CIMMYT), and International Plant Nutrition Institute (IPNI). It enables crop advisers to rapidly develop field-specific fertilizer recommendations for wheat using existing site information. Field evaluation showed that the location-specific nutrient recommendations from the tool increased yield and economic benefits of wheat farmers as compared to the existing practices.

Wheat is the second most important cereal crop next to rice in Asia. Wheat is grown on about 29 M ha in India with an annual production of 81 M t in 2009-10 and an average yield of 2.8 t/ha (FAI, 2011). Recent statistics show that there are considerable yield gaps between the major wheat-growing states in the country with highest yield recorded in Punjab (4.3 t/ha) and lowest in Bihar (2.1 t/ha). In addition, considerable yield gaps exist between researcher-managed optimum NPK plots and farmers' fertilizer practices (FFP, Ladha et al., 2003), indicating a great opportunity for increasing wheat yield and productivity through improved nutrient management practices.

Site-specific nutrient management is a set of nutrient management principles that aims to supply a crop's nutrient requirements tailored to a specific field or growing environment. Its purpose, to (a) account for indigenous nutrient sources, including crop residues and manures; and (b) apply fertilizer 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.

Nutrient Expert is a new, computer-based decision support tool that helps crop advisers formulate fertilizer guidelines based on SSNM principles. NE considers the most important factors affecting nutrient management recommendations in a particular location and enables crop advisers to provide farmers with fertilizer guidelines that are suited to their farming conditions. The tool uses a systematic approach of capturing site information that is important for developing a location-specific recommendation. Yet, NE does not require a lot of data nor very detailed information as in the case of many sophisticated nutrient decision support tools, which could overwhelm the user. It allows users to draw the required information from their own experience, the farmers' knowledge of the local region, and the farmers' practices. NE can use experimental data, but it can also estimate the required SSNM parameters using existing site information. Currently, NE has been applied to hybrid maize for different geographies in Asia and Africa and wheat for South Asia and China.

The objectives of this paper are: 1) to provide a brief description of the conceptual background of the NE nutrient decision support tool, and 2) to demonstrate the performance of NE as applied to wheat by presenting results from on-farm evaluation trials conducted in India.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; M = million; USD = United States dollar; INR = Indian rupee.

Conceptual Background

NE is based on the principles of SSNM as developed for rice (Dobermann and Witt, 2004) and later adapted to maize and wheat. The fertilizer requirement for a field or location is estimated from the expected yield response to each fertilizer nutrient, which is the difference between the attainable yield and the nutrient-limited yield. Nutrient-limited yields are determined from nutrient omission trials in farmers' fields, while attainable yield is the yield in a typical year at a location using best management practices without nutrient limitation. The amount of nutrients taken up by a crop is directly related to its yield (Janssen et al., 1990) so that the attainable yield indicates the total nutrient requirement and the nutrient-limited yield is the yield supported only by the indigenous supply of the concerned nutrient without any external application (Dobermann et al., 2003). The yield response, which is the yield difference between an ample nutrient plot yield and the nutrient omission plot yield, is used as an indirect estimate of the nutrient deficit in soil that must be supplied by fertilizers. NE follows the SSNM guidelines for fertilizer application and split dressings to consider the crop's nutrient demand at critical growth stages. In the absence of trial data for a specific location, NE estimates the attainable yield and yield response to fertilizer from site information using decision rules developed from on-farm trial data.

Information Requirement

NE only requires information that can be easily provided by a farmer or a local expert. The set of information includes:

- Farmers' current yield
- Characteristics of the growing environment or estimate of the attainable yield (if known)
- Soil fertility indicators (e.g. soil texture and color, his torical use of organic inputs) or estimates of yield re sponses to fertilizer N, P, and K (if known)
- Crop sequence in the farmer's cropping pattern
- Crop residue management and fertilizer and organic manure inputs

Nutrient Expert for Wheat (NE Wheat): Database, Design, and Development Approach

We developed SSNM strategies for N, P, and K for wheat using data from 33 locations (with multiple field replicates) in five countries in Asia (IPNI unpublished data). These strategies comprise the algorithm for calculating fertilizer N, P, and

K requirements based on known attainable yield and yield responses. The dataset was also used as the basis for developing the decision rules for estimating SSNM parameters. It provided a range of attainable yields and yield responses to fertilizer N, P, and K across diverse environments characterized by variations in amount and distribution of rainfall, varieties, soils, and cropping systems.

We collaborated with target users and local stakeholders from the early stage of NE development through a participatory approach to ensure that the tool meets the users' needs and preferences, which could increase the likelihood of its adoption. Crop advisers from the public sector and private sector (e.g. fertilizer companies) as well as scientists and extension specialists played an important role in the development of NE Wheat.

NE Wheat has four modules: (1) Current Farmer Fertilization Practice and Yield, (2) SSNM Rates, (3) Sources and Splitting, and (4) Profit Analysis. Each module asks two or more questions and the user selects from a list of options or enters a number in a box. The first two modules include questions that are used to determine the attainable yield and yield responses to fertilizer; and the N, P, and K requirements for the selected attainable yield based on the site information are calculated in the SSNM Rates module. NE Wheat specifies the amount and timing of fertilizer to apply, including split applications in the Sources and Splitting module. It allows users to select a fertilizer source from a list of options and helps to choose sources whose nutrient contents match the requirement for optimal split dressings. And finally it provides a simple ex-ante profit analysis between the existing practice and the improved nutrient management guideline provided by the tool for a particular location.

Table 1. Sites for the field evaluation of Nutrient Expert for wheat under conventional tillage and conservation agriculture practice in India, 2010-2011.

Site no.	State	Cropping system	Field replicate (n)
Conventional tillage			
1	Bihar	Rice – Wheat	11
2	Haryana	Rice – Wheat	15
3	Karnataka	Maize – Wheat	10
4	Punjab	Cotton – Wheat	4
5	Punjab	Rice – Wheat	6
6	Uttar Pradesh	Pearl millet – Wheat	16
Conservation agriculture			
1	Haryana	Rice – Wheat	15
2	Punjab	Cotton – Wheat	4
3	Punjab	Rice – Wheat	8

Table 2. Agronomic and economic performance of Nutrient Expert for wheat (NE) as compared with farmers' fertilizer practice (FFP) and state recommendation (SR) across all sites under conventional tillage in India, 2010-2011.

		Comparison with FFP (n = 46)				Comparison with SR (n = 62)			
Parameter	Unit	FFP	NE	(NE – FFP)†		SR	NE	(NE – SR)†	
Grain yield	t/ha	3.5	4.4	+0.9	***	4.3	4.6	+0.3	***
Fertilizer N	kg/ha	134	141	+6	**	124	141	+16	***
Fertilizer P_2O_5	kg/ha	57	54	–2	ns	64	58	–6	**
Fertilizer K_2O	kg/ha	13	76	+63	***	44	77	+33	***
Fertilizer cost	USD/ha	54	65	+11	***	59	66	+7	***
GRF‡	USD/ha	818	1,039	+221	***	1,023	1,090	+68	***

***, **Significant at 0.001 and 0.01 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 fertilizer costs; estimated using actual local prices of fertilizer and grain at USD 1 = INR 45.

Performance of NE Wheat in Conventional Tillage Areas

In 2010-2011, field evaluation of a beta version of NE Wheat was conducted at six sites under conventional tillage (CT) in the Indo-Gangetic Plains (IGP) representing five states with different cropping systems (**Table 1**). At each site, nutrient management recommendations from NE Wheat were tested against farmers' fertilizer practice (FFP) and the state recommendation (SR) with 4 to 16 field replicates per site and plot sizes of ≥100 m^2. Across all sites, NE Wheat increased yield and economic benefit (i.e. gross return above fertilizer costs or GRF) over FFP and SR (**Table 2**). Compared with FFP, it increased yield by 0.9 t/ha and GRF by 221 USD/ha with slight increase in fertilizer N (+6 kg N/ha) but with large increase in fertilizer K (+63 kg K_2O/ha). Recommendations from NE Wheat also increased yield (by 0.3 t/ha) and GRF (by 68 USD/ha) over SR with moderate increase in fertilizer N (+16 kg N/ha) and substantial increase in fertilizer K (+33 kg K_2O/ha).

Performance of NE Wheat in Conservation Agriculture Areas

NE Wheat recommendations were also tested against FFP and SR at three sites (4 to 15 field replicates per site) practicing conservation agriculture (CA) in 2010-11 (**Table 3**). In India, CA in wheat refers to the practice of zero tillage with or without retention of crop residue from previous crop. Across three sites (n = 27), grain yield and GRF were significantly higher with NE than SR and FFP (**Table 3**). NE Wheat increased grain yield by 0.8 t/ha over FFP and by 0.5 t/ha over SR; and it increased GRF by 180 and 112 USD/ha over FFP and SR, respectively. Average fertilizer N rate was highest with NE and lowest with SR, while average fertilizer K rate was highest with NE (84 kg K_2O/ha) and lowest with FFP (1 kg K_2O) (**Table 3**).

Discussion

Wheat yield improvements with NE Wheat could be attributed to a balanced application of nutrients that is based on nutrient uptake requirement and nutrient supply for a growing environment. Compared with FFP and SR for both CT and CA

Table 3. Agronomic and economic performance of farmers' fertilizer practice (FFP), state recommendation (SR), and Nutrient Expert for wheat (NE) across all sites (n = 27) under conservation agriculture practice in India, 2010-2011.

Parameter	Unit	FFP	SR	NE	P>F†
Grain yield	kg/ha	4.4 b‡	4.7b	5.2a	<.001
Fertilizer N	kg/ha	157b	139c	165a	<.001
Fertilizer P_2O_5	kg/ha	56a	61a	57a	0.387
Fertilizer K_2O	kg/ha	1c	47b	84a	<.001
Fertilizer cost	USD/ha	57	62	73	-
GRF#	USD/ha	1,034b	1,102b	1,214a	<.001

†Statistical analysis was performed with JMP version 8 (SAS Institute, 2009) using Mixed Procedure with sites as random effects.
‡Within rows, means followed by the same letter are not significantly different according to Tukey (0.05)
#GRF refers to the gross return above fertilizer costs; estimated using actual local prices of fertilizer and grain at USD 1 = INR 45.

sites, NE largely increased K, slightly increased N, and did not change P (**Tables 2 and 3**). This suggests that the yield increase was primarily due to the increased application of fertilizer K. Many farmers did not apply K at all (52% of those who participated in CT and 96% of those in CA). The farmers who used fertilizer K, applied it at 19 to 65 kg K_2O/ha, which was less than the average fertilizer K recommended by NE Wheat (76 and 84 kg K_2O/ha for CT and CA, respectively). Fertilizer K application with SR was 30 to 60 kg K_2O/ha depending on the state. The yield increase with NE Wheat over SR seems to indicate that the K recommendations of SR were not sufficient for most of the field locations. The higher GRF in NE than in SR justifies the substantial increase in fertilizer K application.

More importantly, an average increase of 0.3 t/ha would mean an increase of 8.7 M t grain for a total wheat area of 29 M ha, which is a significant contribution to the food supply in the country. NE Wheat provides nutrient recommendations that are tailored to location-specific conditions. In contrast to SR, which gives one recommendation per state (e.g. 120 kg N, 60 kg P_2O_5, and 40 kg K_2O per ha), NE recommends a range of N, P, and K application rates within a site depending on attainable yield and expected responses to fertilizer. The NPK requirement of wheat for a specific field or location is affected by factors in the growing environment such as soil type and farmer's crop management practices. **Table 4** shows that within one site (i.e. Punjab rice-wheat area), fertilizer N, P, and K requirements determined by NE varied among fields or locations.

Summary

Nutrient Expert for Wheat is a nutrient decision support tool that is based on the principles of SSNM. It was developed in collaboration with local stakeholders including scientists, extension agents, and crop advisers from both government and private organizations. NE recommendation takes into account variations in the growing environment that is affected by climate, soil type, cropping system, and crop management practices. NE Wheat provides crop advisers with a simple and rapid tool to apply SSNM principles in individual farmer's wheat field through the use of existing site information. In India, NE Wheat increased yield and economic benefits through balanced application of nutrients that is based on crop requirement. The tool was able to capture the inherent differences between conventional and conservation practices of crop management and site specific nutrient recommendations from NE Wheat performed better than FFP and SR for wheat. Besides providing location specific nutrient recommendations rapidly, the tool has options to tailor advices based on resource availability to the farmers. We expect that the user friendliness of NE Wheat and it's robust estimation of site specific nutrient recommendation will be attractive to extension specialists working with millions of farmers in the intensively cultivated wheat areas in South Asia. BC

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References

FAI, 2011. Fertilizer statistics 2010-11. The Fertilizer Association of India.

Dobermann, A., C. Witt, S. Abdulrachman, H.C. Gines, R. Nagarajan, T.T. Son, P.S. Tan, G.H. Wang, N.V. Chien, V.T.K. Thoa, C.V. Phung, P. Stalin, P. Muthukrishnan, V. Ravi, M. Babu, G.C. Simbahan, M.A.A. Adviento, and V. Bartolome. 2003. Agronomy Journal 95, 924-935.

Dobermann, A. and C. Witt. 2004. *In*: A. Dobermann, C. Witt, D. Dawe. (Eds.), Increasing productivity of intensive rice systems through site-specific nutrient management. Enfield, NH (USA) and Los Baños (Philippines): Science Publishers, Inc., and International Rice Research Institute (IRRI), pp. 75-100.

Janssen, B.H., F.C.T. Guiking, D. Van der Eijk, E.M.A. Smaling, J. Wolf, and H. van Reuler. 1990. Geoderma 46, 299-318.

Ladha, J.K., D. Dawe, H. Pathak, A.T. Padre, R.L. Yadav, and B. Singh. 2003. Field Crops Res., 81: 159-180.

Table 4. Variation in wheat grain yield and fertilizer N, P, and K rates among field replicates at Punjab rice-wheat site. Values in parentheses show the standard deviation of the mean.

		Conventional tillage (n = 6)						Conservation agriculture (n = 8)					
Parameter	Unit	FFP†		SR		NE		FFP		SR		NE	
Grain yield	t/ha	4.0	(0.7)	4.2	(0.8)	4.9	(0.9)	4.2	(0.9)	4.4	(0.7)	5.1	(1.0)
Fertilizer N	kg/ha	147	(6)	125	(0)	155	(16)	149	(6)	125	(0)	159	(16)
Fertilizer P_2O_5	kg/ha	52	(6)	62	(0)	83	(19)	53	(5)	62	(0)	83	(16)
Fertilizer K_2O	kg/ha	5	(12)	30	(0)	91	(11)	4	(11)	30	(0)	89	(10)

†FFP = farmer's fertilization practices; SR = state recommendations; NE = nutrient expert.