Nutrient best management practices for rice, maize, and wheat in Asia

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Abstract
Site-specific nutrient management (SSNM), as developed through more than a decade of research with rice (*Oryza sativa* L.) in Asia, now provides scientific principles on nutrient best management practices for rice, maize (*Zea mays* L.), and wheat (*Triticum aestivum* L.) in Asia. These scientific principles of SSNM enable the pre-season determination of crop needs for fertilizer nitrogen (N), the within-season distribution of fertilizer N to meet crop needs, and the pre-season determination of fertilizer phosphorus (P) and potassium (K) rates to match crop needs and sustain soil fertility. Fertilizer best management for each cereal crop is tailored to field-specific conditions for crop yield, crop residue management, historical fertilizer use, use of organic materials, and nutrient inputs through irrigation water. The widespread uptake by farmers of improved nutrient management requires transforming science-based information into locally adapted tools that enable extension workers, crop advisors, and farmers to rapidly develop and implement best management practices for specific fields and growing conditions. These tools that use information technology and other means for technology dissemination include decision support software, videos, quick guides for fertilizing rice, and the leaf color chart (LCC) for managing fertilizer N.

Key Words
Field-specific nutrient management, BMP, FBMP, fertilizer use efficiency, decision support software, Nutrient Manager.

Introduction
Rice, wheat, and maize are the major sources of calories for the rising human population in Asia. The production of these cereal staples must increase by 1.2% to 1.5% annually to meet rising demand and ensure food security. The closing of exploitable yield gaps through improved use of nutrient inputs is a key technology for helping achieve needed increases in cereal production. The development and widespread rapid uptake by cereal producers of best practices for managing fertilizers is consequently crucial for producing sufficient rice, wheat, and maize at affordable prices for consumers of these cereals and profitability for producers without damaging the environment.

Existing fertilizer recommendations for cereals often consist of predetermined rates of N, P, and K for vast areas. Such recommendations assume that the need of a cereal crop for nutrients is constant over time and over large areas. But, the growth and needs of a crop for supplemental nutrients can vary greatly among fields, seasons, and years as a result of differences in crop-growing conditions, crop and soil management, and climate. Hence, the management of nutrients for cereals requires an approach that enables adjustments in N, P, and K applications to accommodate the field-specific needs of the crop for supplemental nutrients.

More than a decade of research by the International Rice Research Institute (IRRI) and partners on the development, evaluation, and dissemination of site-specific nutrient management (SSNM) for rice across Asia fortunately provides scientific principles on field-specific management of nutrients for cereals. The concept of SSNM for rice emerged in the mid-1990s. It was evaluated and refined from 1997 to 2000 on about 200 irrigated rice farms in eight major rice-growing areas across Asia. From 2001 to 2004, the SSNM concept was systematically transformed to provide farmers and extension workers with locally adapted management of N, P, and K for rice. By 2004, the evaluation and promotion of locally adapted nutrient management practices based on the scientific principles of SSNM reached about 20 locations in Asia representing large areas of intensive rice farming. Improved yields and profitability as well as positive impacts on the environment were demonstrated across Asia (Pampolino *et al*. 2007), and the principles and merits of field-specific nutrient management for rice based on SSNM were widely distributed (Witt *et al*. 2007).

Since 2005, organizations across Asia have used SSNM principles arising from a decade of research on rice to develop and disseminate field-specific nutrient management practices for rice, wheat, and maize. Efforts have focused on harmonization among organizations within a country on nutrient best management

practices, building capacity of technical experts to facilitate the flow of information to local extension, and providing extension workers, crop advisors, and farmers with appropriate tools to quickly develop and implement best management practices for specific fields and growing conditions.

Principles of nutrient management
The SSNM approach provides the scientific principles for determining the amounts of N, P, and K that best match the field-specific needs of a cereal crop for supplemental nutrients. The approach originated from the direct relationship between crop yield and the need of the crop for a nutrient, as determined from the total amount of the nutrient in the crop at maturity (Witt *et al*. 1999). A targeted yield provides an estimate of the total nutrient needed by the crop. The portion of this requirement obtained from non-fertilizer sources is referred to as the indigenous nutrient supply.

The fertilizer N needed by a cereal crop to achieve a profitable target yield is determined from the anticipated yield gain to application of fertilizer N and a targeted efficiency of fertilizer N use to attain the targeted yield. The yield gain is the increase in grain yield due to fertilizer N, which is the difference between the target yield and yield without fertilizer N. Only a fraction of the fertilizer N applied to a cereal is taken up by the crop. Hence, the total amount of fertilizer N required for each tonne of increase in grain yield depends on the efficiency of fertilizer N use by the crop, which is defined as agronomic efficiency of fertilizer N (AEN) — the increase in yield per unit of fertilizer N applied.

The targeted AEN is adjusted for crop and crop response to N — based on results of field trials conducted across Asia in the development and verification of SSNM principles. The targeted AEN for rice typically ranges from a 16 to 25 kg increase in grain yield per kg applied fertilizer N (Witt *et al*. 2007). This corresponds to fertilizer N rates of 40 to 60 kg for a 1 tonne increase in grain yield. The targeted AEN tends to increase with increasing yield gain to N, and with hybrid maize it exceeds 30 kg grain/kg fertilizer N at high attainable responses to fertilizer N of 6 t/ha or more (Witt *et al*. 2009).

The SSNM approach provides guidelines for distributing fertilizer N among critical growth stages in order to match crop needs for supplemental N. With rice, only a small to moderate amount of fertilizer N is recommended within 14 days after transplanting or 21 days after direct sowing. The remaining fertilizer N is distributed to ensure sufficient N at early and mid-tillering to achieve an adequate number of panicles and at panicle initiation to increase grain number per panicle (Witt *et al*. 2007). For wheat, fertilizer N is distributed among pre-emergence, crown root initiation, and tillering stages (Alam *et al*. 2006). For maize, options are proved for application of fertilizer N either as three splits at V0 (0 to 7 days after planting), V6, and V10 stages or as two splits at V0 and V8 stages (Witt *et al*. 2009).

The leaf N content of a cereal crop is closely related to photosynthetic rate and biomass production, and it can serve as an indicator of N demand by the crop during the growing season. The leaf color chart (LCC) is an inexpensive and simple tool for monitoring the relative greenness of a rice leaf as an indicator of the leaf N status (Witt *et al*. 2005). A standardized plastic LCC with four panels ranging in color from yellowish green to dark green has been developed and promoted across Asia (IRRI 2010b). Although the LCC was originally developed for use with rice, it can be used for fine tuning the application of fertilizer N to wheat (Alam *et al*. 2006) and maize (Witt *et al*. 2009).

With the SSNM approach, fertilizer P and K are applied in sufficient amounts to overcome deficiencies and ensure profitable rice farming. Total P and K taken up by the crop are determined from the target yield and an established optimal reciprocal internal efficiency (kg nutrient in above-ground dry matter per tonne grain) for each crop (Witt *et al*. 1999). The total supply of P or K from sources other than fertilizer is estimated from the sum of the nutrient contained in retained crop residues, added organic materials, irrigation water, excess fertilization of the previous crop, and deposited sediment from floods. The difference between the total nutrient (P or K) taken up for the target yield and the nutrient supply provides a nutrient balance. A deficit in a nutrient balance reflects the amount of added nutrient required to avoid net removal of the nutrient from soil.

Fertilizer P and K requirements for a specific field are determined with SSNM using estimated target yield, nutrient balances, and expected yield gains from added nutrient. When yield gain to P or K is negligible, fertilizer P or K requirements are derived solely from the estimated nutrient balance. The nutrient rates can

match maintenance levels (i.e., nutrient input = output in the nutrient balance) when the soil is highly vulnerable to loss of sustained fertility due to nutrient mining. But such maintenance levels are unprofitable in the short term, and options are provided for supplying less than maintenance levels to increase profitability, especially when the soil contains a relatively large exploitable reserve of the nutrient and fertilizer prices are high relative to the cereal price. When yield gain to applied P or K is certain, fertilizer P or K requirements are determined from a combination of the nutrient balance and anticipated yield gain to nutrient application.

Dissemination of best management practices
The ultimate performance indicator of a successful nutrient management strategy is that many farmers quickly obtain and use science-based nutrient best management practices tailored to their specific field, crop, and season. The SSNM approach is a relatively knowledge-intensive technology in which optimum fertilizer management is tailored to field-specific conditions for crop yield, crop residue management, historical fertilizer use, use of organic materials, nutrient inputs in irrigation water, and, in the case of rice, the growth duration of the variety. This knowledge intensity of SSNM has slowed the wide-scale promotion and uptake by farmers of best management practices based on SSNM principles. Uptake by farmers can also be constrained by confusion arising from contrasting recommendations for nutrient management received from different organizations and technical experts.

The widespread uptake by farmers of improved nutrient management requires transforming science-based information into locally adapted tools that enable extension workers, crop advisors, and farmers to rapidly develop and implement best management practices for specific fields and growing conditions. Computer- and Internet-based decision support software capable within 15 minutes of providing farmers with nutrient management guidelines for specific fields with minimized risk and high likelihood of increased profit now form the backbone of locally adapted tools.

Consolidate knowledge into a verified decision tool
Through a partnership of public and private sector organizations in the Philippines, the results from more than a decade of research on SSNM for rice were used in 2008 to develop and verify decision support software targeted for extension and farmers in the Philippines. This decision software titled *Nutrient Manager for Rice: Philippines* was released on CD in 2008, and starting in 2009 it was available on the Internet in English and five dialects of the Philippines (IRRI 2010a). A partnership of organizations in Indonesia similarly developed decision support software tailored to rice production for Indonesia. It was released on CD in Bahasa Indonesia with the title *Pemupukan Padi Sawah Spesifik Lokasi* (*Location-Specific Rice Fertilization*) in 2008.

These decision tools are designed to help extension workers, crop advisors, and farmers quickly formulate fertilizer best management for specific rice fields. Each tool consists of 10–15 questions easily answered by an extension worker or farmer. Based on responses to the questions, a fertilizer guideline with amounts of fertilizer required by crop growth stage is provided for the rice field. Fertilizer rates and timing are adjusted to accommodate a farmer's use of organic sources of nutrients. These tools accommodate transplanted and direct-seeded rice, including inbred and hybrid varieties with a range of growth durations. These tools help farmers increase their yield and profit by applying the right amount of fertilizer at the right time.

The experiences of the Philippines and Indonesia with rice are now being replicated across Asia with rice, maize, and wheat. As of February 2010, decision tools for providing field-specific best nutrient management were under development and verification for wheat in India, maize in Bangladesh, and rice in Bangladesh, China, India, Sri Lanka, Vietnam, and West Africa (IRRI 2010b).

Provide a suite of locally adapted tools
Computer- and Internet-based decision tools are supplemented by a suite of additional locally adapted tools, including videos, quick guides for fertilization, and the LCC for managing fertilizer N. In the Philippines in 2009, *Nutrient Manager for Rice* decision support software was used to develop locally adapted fertilizer guidelines for the most common rice-growing conditions (i.e., crop establishment method, yield level, duration of rice varieties, and crop residue management) in 75 provinces. These guidelines were transformed in local dialects into provincial one-page quick guides for fertilizing rice that were distributed, demonstrated, and promoted in the provinces (IRRI 2010b). As of February 2010, this approach of developing and

disseminating quick guides for fertilizing rice was being replicated in Indonesia.

In 2009, a video titled *Proper Nutrition Makes Healthy Rice Plants* was released in the Philippines to provide farmers with guidelines on nutrient best management for rice (IRRI 2010b). The script was subsequently adapted to Indonesian conditions and a comparable video was released for farmers in Indonesia in the local language. As of February 2010, three additional videos were under development in the Philippines. Scripts from the videos will be circulated to encourage the development of locally adapted videos for farmers in other countries.

Conclusions

Experiences from the Philippines and Indonesia in transforming the scientific principles and research findings of SSNM into tools such as decision support software, videos, and quick guides for accelerating the uptake of nutrient best management serve as a model for replication with rice, maize, and wheat across Asia. Multi-institutional partnerships within the Cereal Systems Initiative for South Asia (CSISA) and the Irrigated Rice Research Consortium (IRRC) together with emerging public-private sector partnerships across Asia provide opportunities for accelerating the development, verification, dissemination, and uptake of locally adapted best nutrient management for cereals across Asia.

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