afa

13TH INT'L ANNUAL FERTILIZERS FORUM

6-8 Feb. 2007

SHARM EL-SHEIKH, EGYPT

Fertilizers Feed the world

13th AFA Int'l Annual Fertilizers Forum &Exhibition

6-8 February 2007

Intercontinental Hotel- Sharm El-Sheikh

Site-specific nutrient management (SSNM) in rice

Roland J. Buresh

International Rice Research Institute,

Philippines

Site-specific nutrient management (SSNM) in rice

Roland J. Buresh
International Rice Research Institute, DAPO Box 7777, Metro Manila, Philippines
Email: r.buresh@cgiar.org

Abstract

Site-specific nutrient management (SSNM) is a plant-based approach, which enables rice farmers to optimally supply their crop with essential nutrients. The optimal supply of nutrients for rice can vary from field-to-field depending on crop and soil management, historical use of fertilizers, management of crop residues and organic materials, and crop cultivar. Hence, the SSNM approach provides the principles and guidelines for tailoring nutrient management practices to specific field conditions.

Optimally supplying rice with essential nutrients as and when needed to achieve high yield and high efficiency of input use involves three steps. The first step is to establish an attainable yield target, which is location and season-specific depending upon climate, rice cultivar, and crop management. This yield target or goal reflects the total amount of nutrients that must be taken up by the crop. The second step is to ensure effective use of existing indigenous nutrients such as from soil, organic amendments, crop residue, manure, and irrigation water. The third step is to apply fertilizer to dynamically fill the deficit between crop needs and indigenous supply and to maintain soil fertility.

The requirement for fertilizer N can be approximated from the response in grain yield to fertilizer N and a targeted efficiency of fertilizer N use. The optimal efficiency of fertilizer N use at maximum profit is often 18 to 25 kg grain yield increase per kg of applied N. The optimal fertilizer N rate for each ton of increase in grain yield is therefore in the range 40 to 55 kg N/ha. The required fertilizer N is apportioned in several doses during the growing season to ensure N supply matches the crop need. The leaf color chart (LCC) is a tool for adjusting fertilizer N use to field-specific needs of rice from tillering onward.

The nutrient omission plot technique is a tool for determining crop requirements for fertilizer P or K. When farmers use less than the estimated crop requirement for a nutrient, a nutrient addition plot technique can be used by farmers to determine the merit of using more of the nutrient. The nutrient addition plot technique is particularly useful for K and micronutrients. Opportunities exist to use farmers' historical use of fertilizer P and K, farmers' straw management practice, yield targets of farmers, and simple field observations to estimate field-specific fertilizer P and K needs. Simple guidelines are needed for using such information together with existing knowledge on soils to empower farmers in using improved practices for their specific rice fields.

The SSNM approach is now being widely promoted through expanded partnerships with research and extension organizations, non-government organizations, and the private sector in Asia. A web site on SSNM (www.irri.org/irrc/ssnm) features the principles for making N, P, and K recommendations, local recommendations developed for major rice-growing areas in Asia, tools and techniques for implementing SSNM, publications, and training materials.

Background

Rice is one of the main staple foods in the world. In 2005, about 620 million metric tonnes of unmilled rice were produced globally on about 150 million ha (FAO, 2006). About 75% of this global production was in the approximately 50% of the production area that is irrigated (IRRI, 2006a). Irrigation together with high-yielding rice cultivars and fertilization have enabled increasing yields of rice, thereby ensuring production of sufficient rice to meet demands without expanding the global area of rice production.

The global demand for rice is expected to continue to grow for many years largely because of population growth (IRRI, 2006a). The increased production of rice to meet demand must therefore come largely from increased yields, particularly in irrigated rice ecosystems, because the scope for increasing rice-growing area is limited due to loss of agricultural land to urbanization and industrialization. In order to achieve higher rice yields to be meet demand and ensure sufficient profitability for farmers, rice production must become more efficient in the use of agricultural inputs, especially essential plant nutrients.

Much of the essential nutrients taken up by rice come from soil and crop residues, but high yields still require the input of supplemental nutrients. The requirement of a rice crop for supplemental nutrients can vary with crop and soil management, cultivar, and climate—which can differ greatly among fields, villages, seasons, and years. Yet, fertilizer recommendations provided to rice farmers typically do not consider field-, climate-, and management-specific effects on the nutrient needs of the crop. Instead, the needs of the crop for nutrients are often assumed to be constant among years and over large areas, and fixed rates and timings of N, P, and K are then recommended for vast areas of rice production.

Soil-based approaches have attempted to tailor fertilizer recommendations to the soil nutrient-supplying capacity of specific fields, as determined through soil-test analyses. Rice, unlike other main food crops, is typically grown on submerged soils. Soil submergence alters biological and chemical processes that influence the release of plant-available nutrients. Soil-test analyses often do not effectively account for these effects of soil submergence on soil nutrient supply and the needs of rice for supplemental nutrients. The quantity of soil nutrient chemically extracted with soil-test analyses is consequently often not as effective for submerged as non-submerged soils in assessing the nutrient needs of the crop. Soil-based approaches also do not provide rice farmers with flexibility to adjust their fertilization practices based on crop performance and climatic conditions during a given season.

Site-specific nutrient management (SSNM) for rice as developed in Asia is a plant-based approach for ‘feeding’ rice with nutrients as and when needed (IRRI, 2006b). The SSNM approach provides the principles and guidelines that enable farmers to apply fertilizer to optimally match the needs of their rice crop in a specific field and season. The SSNM approach does not specifically aim to either reduce or increase fertilizer use. Instead, it aims to apply nutrients at optimal rates and times in order to achieve high rice yield and high efficiency of nutrient use by rice, leading to high cash value of the harvest per unit of fertilizer invested.

The SSNM approach was developed across diverse irrigated rice-growing environments in Asia, where 90% for the world’s rice is produced. Researchers developed the concept of SSNM in the mid 1990s. It was then evaluated and refined from 1997 to 2000 on about 200 irrigated rice farms in eight major rice-growing areas across six countries in Asia (Dobermann et al., 2004). From 2001 to 2004, the initial SSNM concept was systematically transformed to provide farmers and extension workers with simplified plant-need-based management of N, P, and K. This included use of the leaf color chart (LCC) for N management. By 2004, the evaluation and promotion of this simplified SSNM approach had expanded through partnership with national agricultural research and extension systems to about 20 locations across tropical and subtropical Asia, each representing an area of intensive rice farming. The countries involved included Bangladesh, China, India, Indonesia, Myanmar, Thailand, Philippines, and Vietnam. Since 2005, increased emphasis has been placed on the dissemination of SSNM through expanded partnerships with research and extension organizations, non-government organizations (NGOs), and the private sector.

A plant-based approach to nutrient management

With the plant-based SSNM approach the fertilizer N required by a crop can be estimated from the anticipated crop response to fertilizer N, which is the difference between a yield target and yield without fertilizer N—referred to as the N-limited yield.

Yield response to fertilizer N = Yield target – N-limited yield

The yield target is the rice grain yield attainable by farmers with good crop and nutrient management and average climatic conditions for a given location. The N-limited yield can be determined with the nutrient omission plot technique (IRRI 2006b) from the grain yield for a crop not fertilized with N but fertilized with other nutrients to ensure they do not limit yield. When results from the omission plot technique are unavailable, information on use of organic amendments, soil texture, or previous measurements of N-limited yield on similar soils can often be used to suitably estimate N-limited yield. Soil tests are typically not effective for estimating N-limited yield in submerged rice soils (Cassman et al., 1996).

Only a fraction of the fertilizer N applied to rice is taken up by the crop. Hence, the total amount of fertilizer N required for each ton of increase in grain yield depends on the efficiency of fertilizer N use by rice, which is defined as the increase in yield per unit of fertilizer N applied. An efficiency of fertilizer N use of 18 or 20 is often achievable with SSNM and good crop management in farmers' fields in tropical Asia. In high-yielding seasons with very favorable climatic conditions, an efficiency of fertilizer N use of 25 is often achievable with good crop management. Guidelines in estimating fertilizer N required by rice based on grain yield response to fertilizer N and efficiency of fertilizer N use are shown in Table 1.

The plant-based approach of SSNM enables farmers to apply fertilizer N in several doses to ensure the supply of sufficient N is synchronized with the crop need for N at critical growth stages. Young rice before the tillering stage grows slowly and does not need much N. Therefore, with SSNM only a small to moderate amount of fertilizer N is applied to young rice within 14 days after transplanting or 21 days after direct sowing.

In order to achieve high yield, rice plants require sufficient N at early and mid-tillering stages to achieve an adequate number of panicles (grain bunches), at panicle initiation stage to increase grain number per panicle, and during the ripening phase to enhance grain filling. A key ingredient for managing N to meet crop need at these critical growth stages is a method for rapidly assessing leaf N content, which is closely related to photosynthetic rate and biomass production and is a sensitive indicator of the N demand 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., 2005b). A standardized plastic LCC with four panels ranging in color from yellowish green to dark green has been developed through IRRI (Figure 1) and calibrated for many rice cultivars and production systems across Asia (IRRI, 2006b).

The SSNM approach with the LCC developed through IRRI provides two complementary and equally effective options for improved N management using the LCC. In the 'real-time' N management option, farmers monitor the rice leaf color regularly and apply fertilizer N whenever the leaves become more yellowish-green than the critical threshold value indicated on the LCC. In the 'fixed-time/adjustable dose' option, the time for N fertilization is pre-set at critical growth stages, and farmers adjust the dose of N upward or downward based on the leaf color. The selection of an option for using the LCC can be based on farmer preferences and location-specific factors. The fixed-time/adjustable-dose option, for example, is less time-consuming and is preferred by farmers with gainful non-rice activities and insufficient time for weekly visits to their rice fields. The real-time option is generally preferred when farmers lack sufficient understanding of the critical stages for optimal timing of fertilizer N. The effective management of N with both approaches, however, requires sufficient application of P, K, and micronutrients to overcome limitations of other nutrients.

In the plant-based SSNM approach fertilizer P and K are applied in sufficient amounts to overcome deficiencies and maintain soil fertility. The need of the rice crop for fertilizer P in a given field or location is obtained from an estimate of an attainable yield target and a P-limited yield. The need of the rice crop for fertilizer K is similarly obtained from an estimate of an attainable yield target and a K-limited yield. The yield target is the rice grain yield attainable by farmers with good crop and nutrient management and average climatic conditions. It provides an estimate for the total amounts of P and K needed by the rice crop because the amounts of P and K taken up by a rice crop are directly related to crop yield. The yield target can be estimated from the grain yield in a fully fertilized plot with no nutrient limitations and good management.

Because rice grain yield is directly related to the total amount of P taken up by rice, the P-limited yield approximates the P supplied to rice from indigenous sources such as soil, crop residue, irrigation water, organic amendments, and manures. The P-limited yield and hence indigenous P supply can be determined from grain yield for a crop not fertilized with P but fertilized with other nutrients to ensure they do not limit yield. The K-limited yield similarly approximates the K supplied to rice from indigenous sources. The K-limited yield and hence indigenous K supply can then be estimated from grain yield for a crop not fertilized with K but fertilized with other nutrients to ensure they do not limit yield. Irrigation water can be an important indigenous source of K that is taken accounted for with K-limited yield in the SSNM approach but not with soil testing.

The attainable yield target and P-limited yield are used with a nutrient decision support system (Witt et al., 2005a) to determine the amount of fertilizer P_2O_5 required to both overcome P deficiency and maintain soil P fertility. Outputs of the nutrient decision support system are summarized in Table 2 (Witt et al., 2002). Similarly, the attainable yield target and K-limited yield, together with an estimate of the amount of retained crop residue, are used to determine the amount of fertilizer K_2O required to both overcome K deficiency and maintain soil K fertility. Outputs of the nutrient decision support system are summarized in Table 3 (Witt et al., 2002).

Performance of SSNM in Asia

The use of SSNM, as compared to existing farmers' fertilizer practices, has consistently increased rice yields and profitability of rice farming across major rice-growing areas in Asia. Increased yields and profit were typically associated with changes in fertilizer timing and rates to better match the needs of the rice crop for supplemental nutrients. In some cases, the use of SSNM also reduced rice disease and pests.

In the Red River Delta of northern Vietnam, as an example, SSNM was compared with the existing farmers' fertilizer practices on 60 farms across five soil types for two years (2003–2004) with two rice crops per year. SSNM increased average annual yield of rice by 0.8 t/ha or 6%. The added net benefit from use of SSNM averaged 147 US$/ha per year. With SSNM, the application of fertilizer K was increased about 20%, and the application of fertilizer N was reduced about 25%. The national integrated pest management (IPM) project has included the technology in its farmers' field schools and distributed LCCs to 50,000 farmers.

The use of SSNM, as compared to existing farmers' fertilizer practices, also increased rice yield in farmers' fields in the Cauvery Delta of southern India, in Central Luzon in the Philippines, and in the Mekong Delta of southern Vietnam. The increase in annual grain yield with use of SSNM in on-farm evaluation trials averaged 0.9 t/ha in southern India, 0.7 t/ha in the Philippines, and 0.7 t/ha in southern Vietnam (Pampolino et al., 2007). Based on group discussions with farmers practicing SSNM and with other farmers not practicing SSNM, the added net annual benefit due to use of SSNM was 168 US$/ha in India, 106 US$/ha in the Philippines, and 34 US$/ha in Vietnam. In southern India, farmers practicing SSNM reduced their use of pesticides. Use of on-farm data from the sites with a simulation model (DNDC; Denitrification-Decomposition) suggested lower N loss from applied fertilizers with SSNM. The model also suggested that the use of SSNM could reduce the emissions of nitrous oxide—a greenhouse gas—per unit of grain produced (Pampolino et al., 2007).

Dissemination of SSNM

Rice farmers in Asia typically lack sufficient knowledge on the most effective use of fertilizers for their fields. Their resulting ineffective use of fertilizer can limit their profit from rice farming and increase the susceptibility of their rice crop to diseases and pests. The SSNM approach is now being widely promoted through expanded partnerships with research and extension organizations, non-government organizations, and the private sector in Asia in order to empower farmers with decision-making skills for their specific rice-growing conditions.

The effective uptake by farmers of a relatively knowledge intensive technology such as improved nutrient management for rice necessitates the communication of consistent and clear messages to farmers. This requires ensuring the persons providing farmers with information on nutrient management are familiar with the SSNM guidelines and how they can be used by farmers to develop improved practices for specific rice fields. The dissemination of SSNM therefore starts with the training of researchers, local extension workers, fertilizer retailers, and farmer leaders on techniques and guidelines for enabling rice farmers to use effective nutrient management practices for their specific rice-growing conditions. A web site provides technical information on the SSNM approach, nutrient management recommendations developed from past research for major rice-growing areas across Asia, and guidelines for tailoring nutrient management to field-specific conditions (IRRI, 2006b). Literature on tools and techniques for implementing SSNM has been prepared in local languages across Asia.

Trained researchers, extension workers, fertilizer retailers, and farmer leaders are encouraged to interact with farmers in a participatory fashion, which empowers farmers to identify and evaluate nutrient management practices tailored to their specific rice fields. Demonstration plots in farmers' fields can provide farmers with visible evidence for the merits of an alternative nutrient management practice. Farmer participation is encouraged in selecting the field for such demonstrations and the nutrient management practices to be examined.

Relatively high rice yields are being obtained in a number of Asian rice-growing areas with insufficient application of K, S, and micronutrients to match the crop removal and export of these nutrients. In such cases, the mining of soil nutrients is often presumed to not adversely affect yields and profit from rice farming. The adoption of improved management for rice, including improved fertilizer N and P practices such as provided with SSNM, enables farmers to further increase their yields and profit for rice farming. But, deficiencies of K, S, and micronutrients can become increasingly more important in constraining the attainment of the high yields and profit possible with improved fertilizer N and P practices. Experiences across Asia in implementing SSNM confirm that uncertainty often exists at the field and farm level regarding the optimal rate for fertilizer K and whether to apply a micronutrient such as zinc. In such cases, especially when it is suspected that farmers are not applying sufficient quantity of a nutrient, the nutrient addition plot technique can be used by farmers to determine the merit of using more of the nutrient (IRRI, 2006b).

The nutrient addition plot technique involves superimposing a small plot, typically about 5 m by 5 m, within a farmer's field. The nutrient of interest is applied within this addition plot, and the rice crop is otherwise managed by the farmer identically inside and outside the plot area. With K, for example, the entire farmer's field typically receives fertilizer K using the farmer's current practice whereas the addition plot receives additional fertilizer K. Farmers can then compare crop performance inside and outside the addition plot. Rice yield can be limited by insufficient supply of K even when symptoms of K deficiency are not visible during crop growth. Farmers are therefore encouraged to compare grain filling and recovery of milled grain between the plot with additional K and their adjacent field without additional K because the benefits of K on yield and profit often emerge through higher percentage of filled grain rather than a higher number of total grains.

We strive through the process of disseminating SSNM to empower farmers with greater decision-making skills for their specific rice-growing conditions. Field visits and farmer meetings are encouraged together with the use of simple observational tools such as nutrient additional plots. We plan in the future to develop more effective ways for farmers to utilize knowledge of their historical use of fertilizer P and K, their straw management practice, yield targets, and simple field observations to help them identify improved nutrient management practices for their specific rice fields.

The current dissemination of SSNM for rice builds upon a decade of research and partnerships across Asia beginning with the development and testing of a plant-based concept followed by on-farm evaluations, adaptive research for tailoring recommendations to local needs and conditions, training, building awareness at provincial and national levels, and developing clear and consistent messages for local extension and farmers. The long-term process that systematically established the scientific basis for SSNM, evaluated and refined SSNM in farmers' fields through partnerships across Asia, and is now

disseminating improved nutrient management for rice across Asia has been made possible through a decade of support from the Swiss Agency for Development and Cooperation (SDC), the International Fertilizer Association (IFA), the Potash and Phosphate Institute (PPI-PPIC), and the International Potash Institute (IPI).

References

Cassman KG, Dobermann A, Sta Cruz PC, Gines GC, Samson MI, Descalsota JP, Alcantara JM, Dizon MA, Olk DC. 1996. Soil organic matter and the indigenous nitrogen supply of intensive irrigated rice systems in the tropics. Plant Soil 182:267–278.

Dobermann A, Witt C, Dawe D (eds). 2004. Increasing the 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).

FAO (Food and Agriculture Organization). 2006a. FAOSTAT: crops. http://faostat.fao.org. Accessed 30 December 2006.

IRRI (International Rice Research Institute). 2006a. Bringing hope, improving lives. Strategic Plan 2007–2015. Manila (Philippines): IRRI.

IRRI (International Rice Research Institute). 2006b. Site-specific nutrient management. http://www.irrri.org/irrc/ssnm. Accessed 30 December 2006.

Pampolino MF, Manguiat IJ, Ramanathan S, Gines HC, Tan PS, Chi TN, Rajendran R, Buresh RJ. 2007. Environmental impact and economic benefits of site-specific nutrient management (SSNM) in irrigated rice systems. Agricultural Systems 93:1–24.

Witt C, Balasubramanian V, Dobermann A, Buresh RJ. 2002. Nutrient management. pp 1-45. In Fairhurst TH, Witt C (eds.) Rice: a practical guide to nutrient management. Singapore and Los Baños (Philippines): Potash and Phosphate Institute (PPI), Potash and Phosphate Institute of Canada (PPIC), and International Rice Research Institute (IRRI).

Witt C, Fairhurst TH, Sheehy JE, Dobermann A, Gfroerer-Kerstan A. 2005a. A nutrient decision support system software for irrigated rice. Better Crops. 4:26–28.

Witt C, Pasuquin JMCA, Mutters R, and Buresh RJ. 2005b. New leaf color chart for effective nitrogen management in rice. Better Crops 89 (no. 1): 36–39.

Table 1. Guidelines for estimating total fertilizer N required for rice based on yield response to fertilizer N and efficiency of fertilizer N use.

Efficiency of fertilizer N use (kg grain increase kg^{-1} applied N) →	15	18	20	25
Yield response ($t\ ha^{-1}$) ↓	Fertilizer N rate ($kg\ ha^{-1}$)			
1	65	55	50	40
2	130	110	100	80
3	195	165	150	120
4		220	200	160
5			250	200

Table 2. Guidelines for the application of fertilizer P_2O_5 according to yield target and P-limited yield in P omission plots (Witt et al. 2002).

Yield target (t/ha) →	4	5	6	7	8
P-limited yield (t/ha) ↓	Fertilizer P_2O_5 rate (kg/ha)				
3	20	40	60		
4	15	25	40	60	
5	0	20	30	40	60
6	0	0	25	35	45
7	0	0	0	30	40
8	0	0	0	0	35

Table 3. Guidelines for the application of fertilizer K_2O according to yield target and K-limited yield in K omission plots (Witt et al. 2002).

Rice straw inputs	Yield target (t/ha) →	4	5	6	7	8
	K-limited yield (t/ha) ↓	Fertilizer K_2O rate (kg/ha)				
Low (< 1 t/ha)	3	45	75	105		
	4	30	60	90	120	
	5	0	45	75	105	135
	6	0	0	60	90	120
	7	0	0	0	75	105
	8	0	0	0	0	90
Medium (2–3 t/ha)	3	30	60	90		
	4	0	35	65	95	
	5	0	20	50	80	110
	6	0	0	35	65	95
	7	0	0	0	50	80
	8	0	0	0	0	65
High (4–5 t/ha)	3	30	60	90		
	4	0	30	60	90	
	5	0	0	30	60	90
	6	0	0	10	35	70
	7	0	0	0	25	55
	8	0	0	0	0	40

Figure 1. A standardized leaf color chart (LCC) for N management in rice (© IRRI, 2005).