Improving Nutrient Management Strategies for Delivery in Irrigated Rice in Asia

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An important task is to package the scientific principles of site-specific nutrient management (SSNM) into guidelines for extension workers and farmers.

Fertilizer management in irrigated rice in Asia requires both preventive and corrective nutrient management strategies. Crop response to fertilizer application is not always easy to predict due to the effects of seasonal and year-to-year variation in climate (particularly solar radiation), and spatial and temporal variation of indigenous soil nutrient supplies. Both factors lead to large differences among sites, seasons, and years in optimal rates for fertilizer inputs. Current fertilizer recommendations in Asia, however, typically consist of blanket recommendations with fixed rates and timings for large rice-growing areas.

Considerable progress has been made in recent years in developing field- and season-specific nutrient management approaches, as alternatives to blanket recommendations for nitrogen (N), phosphorus (P), and potassium (K) fertilizers (Balasubramanian et al., 1999; Dobermann et al., 2002). These techniques have been evaluated in a wide range of farmer fields in Asia and are now positioned for wider scale validation and farmer adaptation. This article summarizes current efforts to refine and simplify the underlying principles of SSNM into tools and guidelines for improved nutrient management in Asia's irrigated rice systems.

Note: Part 1 and Part 2 of this series of articles on Site-Specific Nutrient Management (SSNM) for rice in Asia appeared in *Better Crops International*, 2002, No. 1.

Principle 1: Yield gains and fertilizer requirements

The principle described here provides a basic plan for the pre-season calculation of balanced fertilizer rates, based on the difference between the rice plant's nutrient requirements and the soil's nutrient supplying capacity. This deficit depends largely on the expected yield increase, which we define as the difference between the nutrient limited yield and the season-specific yield goal. Yield gains must be estimated separately for N, P, and K to take into account differences in the supply of each nutrient. For example, if the nutrient-limited yield measured in omission plots (see Principle 2) was 5 t/ha for P and 6 t/ha for K, the required yield increase to achieve a yield goal of 6 t/ha would be 1 t/ha for P and 0 t/ha for K. Thus, sufficient fertilizer P must be applied to support the required yield increase, whereas sufficient K must be applied to prevent the long-term depletion of soil K (see Principle 4).

As a rule of thumb, we estimate that 40 kg fertilizer N, 20 kg P_2O_5, or 30 kg K_2O are required to raise the respective nutrient-limited yield by 1 t/ha. These fertilizer rates were calculated based on the approach described by Witt and Dobermann (2002a):

$FN = (GY-GY_{0N}) \times UN / REN$ [equation 1]

$FP = (GY-GY_{0P}) \times UP / REP \times 2.292$ [-15%] [equation 2]

$FK = (GY-GY_{0K}) \times UK / REK \times 1.2$ [-15%] [equation 3]

where FN, FP, and FK are the recommended fertilizer N, P_2O_5, and K_2O rates in kg/ha; GY is the desired yield goal (t/ha); GY_{0N}, GY_{0P} and GY_{0K} are the grain yields measured in nutrient omission plots (0-N, 0-P, 0-K) (t/ha); UN, UP, and UK are the plant uptake requirements of 15 to 20 kg N, 2.6 kg P, and 15 kg K per t grain yield; and REN, REP and REK are the expected fertilizer recovery efficiencies of 40 to 50% for N, 25% for P, and 50% for K. Fertilizer P and K rates were finally reduced by 15% because previous on-farm research has shown that the desired yield goal will not be reached every season due to constraints other than nutrient management (e.g., climate, pests, etc.). Such simple rules are only valid under the following assumption: a yield goal was chosen according to the guidelines outlined by Witt and Dobermann (2002b); moderate to high N efficiencies can be reached with improved nutrient management under field conditions; soil P and K fixation is low to moderate; K losses due to leaching are small; about 4 to 5 t straw/ha is returned after each harvest (incorporated or burned).

Principle 2: Use of omission plots for estimating soil nutrient supplies

Soil nutrient supplies can be estimated indirectly from plant nutrient uptake in omission plots as an alternative to soil testing (Witt and Dobermann, 2002b). Plant-based estimates of soil nutrient supply integrate the supply of all indigenous sources estimated under field conditions and also offer the possibility for estimating the nutrient supplying power of organic manures. For the purpose of extension, soil nutrient supply can be estimated from grain yield in omission plots, assuming an average uptake of 15 kg N, 2.6 kg P, and 15 kg K at harvest per tonne of grain yield/ha (Dobermann and Fairhurst, 2000), or expressed as nutrient-limited yield in the respective omission plot. A major advantage of this approach is that the soil supply is expressed in a unit that can be used directly in the calculation of fertilizer requirements (see Principle 1). Furthermore, soil nutrient supply becomes visible to farmers and thus omission plots are a simple and effective demonstration tool for use by extension workers (see photo).

Installation of nutrient omission plots.

Principle 3: Need-based N management

Asian farmers generally apply fertilizer N in several split applications, but the number of splits, amount of N applied per split, and the time of application vary considerably even within small recommendation domains. Farmer flexibility in adjusting the timing and amount of fertilizer applied offers great potential to synchronize N application with the demand of the rice crop in real-time. In the following, we discuss the three most important N management strategies.

a) **Location-specific N fertilizer splitting schedules for preventive N management** follow a fixed schedule of fertilizer N applications. Such recommendations for location-specific N regimes are in wide spread use, usually developed on-station or on-farm in N fertilizer response experiments. Limitations of fertilizer response experiments include costly and time consuming identification of optimal fertilizer splitting patterns and corresponding fertilizer N rates, and limited potential to extrapolate results due to wide variation in both soil N supply, within large recommendation domains, and crop response due to climatic factors.

Corrective N management strategies offer greater potential for efficient fertilizer N management (see below), but recommendations for location-specific N schedules may be sufficiently accurate under stable climatic conditions with low pest pressure, or where large benefits can be expected from rather crude adjustments in fertilizer N management, such as sites in Zhejiang, China, where fertilizer N use was excessive.

Location-specific split schedules can be developed following Principles 1 and 2 above, where fertilizer N requirements are calculated based on crop requirements and soil indigenous N supply. An estimate of the latter may be obtained by analyzing current farm yields and farmer N management strategies (Dobermann and Fairhurst, 2000) in combination with local knowledge on soil fertility. Thus, N omission plots may not be required to obtain a sufficiently accurate estimate of indigenous N supply. Locally refined N splitting patterns have to take into account specific needs for differences in climatic seasons, varieties, crop establishment, basal N application, and water management (Dobermann and Fairhurst, 2000).

b) **Real time corrective N management** with a leaf color chart (LCC) requires periodic assessment of plant N status, and the application of fertilizer N is delayed until N deficiency symptoms start to appear. This need-based approach to N management does not require the estimation of soil N supply or the calculation of a preseason fertilizer rate. The scientific basis for need-based N management was developed with the introduction of the chlorophyll (SPAD) meter (Peng et al., 1996; Balasubramanian et al., 1999). The costly SPAD meter is not suitable as an on-farm tool, however, and a LCC, modified from prototypes

Leaf color chart.

developed in Japan (Furuya, 1987) and China (by Prof. Tao Qinnan, Zhejiang University) was developed recently through the International Rice Research Institute (IRRI) and the National Agricultural Research and Experimental Systems (NARES) collaboration (IRRI, 1999). Leaf color is a visual and subjective indicator of plant N deficiency, and the LCC, with its six color panels of different shades of green, is used as a reference tool (see photo).

Need-based N management requires the identification of an optimal leaf color that must be maintained throughout the season to obtain high yields. The optimal leaf color (or critical LCC value) varies depending on cultivar and crop establishment method. Guidelines for the use of the LCC include reading of leaf color at seven to 10 day intervals from early tillering until flowering. When the average leaf color of sampled leaves falls below the critical value, a predetermined amount of N fertilizer is applied immediately to correct N deficiency. Standard corrective application rates (less than 40 kg N/ha to ensure efficient fertilizer N use) that take into account yield potential were developed for each season. Large numbers of LCCs have been fabricated and distributed to farmers through collaboration with NARES in several Asian countries. Several versions of LCCs currently exist (IRRI, Japan, China, and University of California Cooperative Extension), and research efforts at IRRI are underway to compare LCCs and explore options for refining and standardizing colors.

c) Location-specific split schedules combined with LCC provide tools for preventive and corrective N management. Total fertilizer N requirements are calculated as described for location-specific split schedules (see above), including guidelines for the need of basal N application. Predetermined N doses are adjusted during later growth stages depending on the plant requirement for fertilizer N. This dual strategy is similar to the SPAD meter approach described by Witt and Dobermann (2002b). Using schedules in addition to the LCC may address some farmer preferences and needs to reduce reliance on frequent visits to the field. Clearly, the most suitable strategy may vary from location to location and will have to be identified through farmer evaluation and validation, and an economic analysis of the strategies tested.

Principle 4: Sustainable crop- and soil-based P and K management

The estimation of P and K requirements is challenging for individual farmers due to small land holdings and substantial variation in the supply of soil P and K within small recommendation domains. Information on soil nutrient supply is particularly important for P and K, because of the difficulty of predicting short- and long-term crop responses to P and K application, and less possibility to correct P and K deficiencies within the cropping period, as compared with N.

In general, nutrient use efficiency is greatest when all P and most K fertilizer is applied early in the season to avoid deficiencies at early growth stages. This requires a conceptual framework to guide farmers in the estimation of season-specific total fertilizer P and K requirements.

Nutrient omission plots placed in representative farmer fields help extension workers to develop an improved understanding of the variability in soil fertility within a recommendation domain in partnership with farmers. The yield gain concept then provides a simple rule for predicting fertilizer requirements (Principle 1). Problems remain, however, with regard to strategies geared towards the long-term maintenance of soil nutrient reserves where a direct crop response to P and K application is not expected.

A simple nutrient balance model was constructed based on the nutrient requirements for targeted yield goals, taking into account the soil nutrient supply estimated from a nutrient omission plot, nutrient inputs from irrigation water, and nutrient removal with grain and straw:

$$FP = GY \times UP - StP + (GY\text{-}GY_{0P}) \times UP \times 2.292 \quad [-15\%] \quad [equation\ 4]$$

$$FK = GY \times UK - StK - WK + (GY\text{-}GY_{0K}) \times UK \times 1.2 \quad [-15\%] \quad [equation\ 5]$$

where StP and StK are the estimated inputs of 0.85 kg P and 13 kg K per t recycled straw, and WK is the average K input with irrigation water during the growing season. See equations 1-3 for further abbreviations. An average input of 25 kg K/ha per crop with irrigation water is assumed here, based on measurements conducted at various sites in Asia, but measurements should be made in each locality. It was further assumed that K input from rainfall equals K losses due to percolation. Fertilizer P and K rates were finally reduced by 15% because of the rules explained under Principle 1. Suggested recommendations for maintenance P and K rates are presented in **Tables 1** and **2**, and minimum P and K rates for yield increases were set to 20 kg P_2O_5 and 30 kg K_2O/ha/t yield (Witt and Dobermann, 2002a).

Rice straw contains relatively little P, so that only a simplified table is presented for cases where only small amounts of straw (2 to 3 t/ha) are returned to the soil (**Table 1**). The fertilizer P requirement largely depends on the deficit between yield goal and soil nutrient supply, and the suggested maintenance fertilizer P rates for conditions where a direct crop response is not expected (yield goal = yield in 0 P plot) increase slightly with an increase in the yield target.

Straw management has a pronounced effect on the maintenance of soil K supply (**Table 2**), because about 80% of the K taken up by the rice plant remains in the straw. Bulk straw incorporation or wide-spread burning has similar positive effects on P and K recycling (Dobermann and Fairhurst, 2000). Where only small amounts of straw are incorporated after harvest (e.g., Bangladesh, India, Nepal, and North

Vietnam), substantial amounts of fertilizer K would have to be added to balance K removal in straw and grain. Where the amount of straw incorporated is 4 to 5 t/ha, fertilizer K application would only be required if a crop response is expected, and a minimum rate of 30 kg K_2O/ha/t grain yield increase is sufficient (see Principle 1).

Table 1. Maintenance fertilizer P_2O_5 rates (kg/ha) depending on yield in 0-P plots and yield goal.

Yield in 0-P plots, t/ha	Yield goal, t/ha 4	5	6	7	8
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

* A lower yield goal is recommended when the required yield increase exceeds 3 t/ha.

The model takes the most relevant input and output parameters into account, and assesses more accurately such important issues as long-term mining and replenishment of soil P and K reserves (Witt and Dobermann, 2002a). Local adaptation and refinement of these generic principles may be required to integrate results of local research (e.g., soil P and K supplying capacity determined in long-term experiments).

Principle 5: Increasing profitability

The major benefit for farmers from improved nutrient management strategies can be expected as an increase in the profitability of rice cropping (Dobermann et al., 2002). The principles of SSNM can accommodate a wide range of socio-economic conditions, including situations of labor shortage. Small amounts of additional labor may be required, but labor costs for nutrient management are relatively small compared to those for land preparation, transplanting or harvesting. Efficient N management may also result in off-farm environmental benefits through a reduction of fertilizer N use without a reduction in yield (Balasubramanian et al., 2000, Wang et al., 2001), especially in situations where N inputs are very large (e.g., China and Java Island in Indonesia). This may increase profitability, particularly in cases of very high fertilizer N inputs (China, Indonesia).

Large reductions in N use in such locations may also increase farm profits, but the cost of fertilizer N is typically less than 7% of the gross revenue from paddy (Dawe, 2001). Thus, a 20% saving in fertilizer N represents less than 2% of gross revenue. The major potential for

Table 2. Maintenance fertilizer K_2O rates (kg/ha) depending on yield in 0-K plots, yield goal, and amount of incorporated straw.

Yield in 0-K plots, t/ha	Yield goal, t/ha: low straw return (0-1 t/ha)					medium straw return (2-3 t/ha)					high straw return (4-5 t/ha)				
	4	5	6	7	8	4	5	6	7	8	4	5	6	7	8
3	45	75	105	*	*	30	60	90	*	*	30	60	90	*	*
4	30	60	90	120	*	0	35	65	95	*	0	30	60	90	*
5	0	45	75	105	135	0	20	50	80	110	0	0	30	60	90
6	0	0	60	90	120	0	0	35	65	95	0	0	10	35	70
7	0	0	0	75	105	0	0	0	50	80	0	0	0	25	55
8	0	0	0	0	90	0	0	0	0	65	0	0	0	0	40

* A lower yield goal is recommended when the required yield increase exceeds 3 t/ha.

increasing farm profitability through innovative nutrient management lies in increasing yield through efficient N management and balanced nutrition. To select the most profitable strategies, farmer participatory evaluation of innovative nutrient management should be accompanied by an evaluation of fertilizer costs comparing combined and straight fertilizers and a gross margin analysis.

Summary

The principles of SSNM were developed through on-farm evaluation in partnership with National Agricultural Research and Extention Systems (NARES) in the workgroup Reaching Toward Optimum Productivity (RTOP) of the Irrigated Rice Research Consortium (IRRC) and the Crop and Resource Management Network (CREMNET). The strategies outlined here can be adapted for use across a wide range of cropping conditions in rice-based systems, including those where large amounts of organic nutrient sources are used.

IRRI is involved in wider-scale farmer evaluation and adaptation of SSNM through partnership with NARES, as part of the IRRC, and through the rice-wheat consortium (RWC). Interdisciplinary NARES teams are involved in on-farm evaluation of innovative nutrient management strategies in Bangladesh, China, India, Indonesia, Nepal, Pakistan, the Philippines, Thailand, and Vietnam. Involvement of public and private sector partners is being strengthened to facilitate dissemination of information and delivery of SSNM to rice farmers. **BCI**

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