Performance of Site-Specific Nutrient Management in Intensive Rice Cropping Systems of Asia

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A site-specific approach to nutrient management was evaluated in 179 on-farm experiments with irrigated rice in China, India, Indonesia, Thailand, the Philippines, and Vietnam. The agronomic and economic performance of the new approach was compared with current farmer fertilizer practices for four crops.

Soil nutrient supplies, fertilizer efficiency, and productivity vary widely across small distances in the diverse irrigated rice fields in Asia. At present, however, blanket fertilizer recommendations are often applied over large areas without taking into account the wide variability and site- and season-specific crop nutrient requirements within each recommendation domain. This helps to explain why fertilizer nitrogen (N) use efficiency is usually poor, the use of potassium (K) fertilizers is often not balanced with crop requirements and other nutrients and, as a result, profitability is not optimised (Dobermann et al., 1998; Olk et al., 1999).

Based on these conclusions, drawn from three years of on-farm research in five Asian countries, the International Rice Research Institute (IRRI) together with National Agricultural Research and Extension Systems (NARES) partners launched a research project in 1997 to develop site-specific nutrient management (SSNM) technology for intensive rice systems (Witt and Dobermann, this issue). A series of on-farm experiments was conducted in six Asian countries to test the hypothesis that rice yields, profit, plant nutrient uptake, and fertilizer efficiencies can be increased significantly through field- and cropping season-specific nutrient management. In this article, we evaluate the performance of SSNM compared to prevailing farmer practices.

Materials and Methods

On-farm experiments were conducted in major rice production domains with at least two rice crops per year in Jinhua (Zhejiang, China), Maligaya (Nueva Ecija, the Philippines), Suphan Buri (Thailand), Omon (Mekong Delta, South Vietnam), Hanoi (Red River Delta, North Vietnam), Sukamandi (West Java, Indonesia), and Aduthurai and Thanjavur (Tamil Nadu, South India). The experimental set-up followed a

Table 1. Plant-based estimates of potential soil indigenous N, P, and K supplies derived from omission plots (179 farms, two seasons) in 1997-1998.

	Minimum	25% quartile	Median	75% quartile	Maximum
Plant N uptake in 0-N plots, kg/ha	29	52	64	76	107
Plant P uptake in 0-P plots, kg/ha	7	14	17	20	32
Plant K uptake in 0-K plots, kg/ha	43	74	90	109	198
Grain yield 0-N plots, t/ha	1.8	3.8	4.5	5.2	6.5
Grain yield 0-P plots, t/ha	2.7	4.5	5.7	6.7	8.2
Grain yield 0-K plots, t/ha	2.6	4.6	5.6	6.6	8.8

standard protocol at all sites and included nutrient omission plots (0-N, 0-P, 0-K) to estimate indigenous nutrient supplies, a SSNM treatment, and farmer fertilizer practice (FFP) in each farmer field. Researchers did not intervene in the FFP plots but managed fertilizer application in the SSNM and nutrient omission plots. Farmers were responsible for all other aspects of general crop and pest management and the choice of variety. Treatments (SSNM and FFP) were compared on 179 farms over a period of four cropping seasons during 1997 to 1999 (Dobermann et al., 2002a; 2002b).

An estimate of soil indigenous N, phosphorus (P), and K supply was obtained from omission plots situated in each farmer field. The results from these plots were used as inputs in a model designed to estimate field-specific fertilizer requirements in the SSNM plots (Witt and Dobermann, this issue).

Soil nutrient supplies varied widely, and two- to three-fold ranges were found for each nutrient and site (**Table 1**). Average soil nutrient supplies, based on measurements of plant nutrient uptake at all sites, were 64 kg N, 17 kg P, and 90 kg K per ha per crop. Over all sites, grain yield without N application ranged from less than 2 t/ha to more than 6 t/ha, with a median of 4.5 t/ha. Average grain yield in 0-P and 0-K plots was about 5.7 t/ha, but soil P and K supplies were sufficient for grain yields of only 4.5 t/ha on 25 percent of the farms. For comparison, current average yields in irrigated rice are about 5.3 t/ha. While these results confirm the primary importance of N in irrigated rice, P and K appear to be equally limiting in many parts of South and Southeast Asia.

Table 2. Agronomic and economic performance indicators.

Indicator	Unit	Interpretation
Increase in grain yield	t/ha or %	Gross productivity
Achievement of yield goal	% of yield goal	Climatic variability and quality of crop management
Internal nutrient efficiency	kg/kg	Balanced nutrition within the plant, occurrence of other stresses
Nitrogen use efficiency (AEN, PEN, REN)	kg/kg	Congruence of N supply and crop N demand; negative effects on the environment
Input-output balance of P and K	kg/ha/crop	Medium- and long-term sustainability of soil productivity
Gross return over fertilizer cost (GRF)	US$/ha/crop	Financial profitability

Performance indicators were used for the agronomic and economic evaluation of SSNM and FFP (**Table 2**):

- Internal N efficiency (IEN) is the grain yield produced per unit N taken up by the plant (kg grain/kg plant N).
- Recovery efficiency of fertilizer N (REN) is the increase in plant N uptake per unit fertilizer N applied (kg plant N/kg fertilizer N).

• Physiological N efficiency (PEN) is the increase in grain per unit increase in plant N uptake from fertilizer (kg grain/kg plant N).

• Agronomic N use efficiency (AEN) is the product of REN and PEN, expressed as the yield increase per unit fertilizer N applied (kg grain yield/kg fertilizer N).

• Gross return over fertilizer costs (US$/ha/crop) is calculated as revenue (grain yield x farm gate paddy price) minus fertilizer cost.

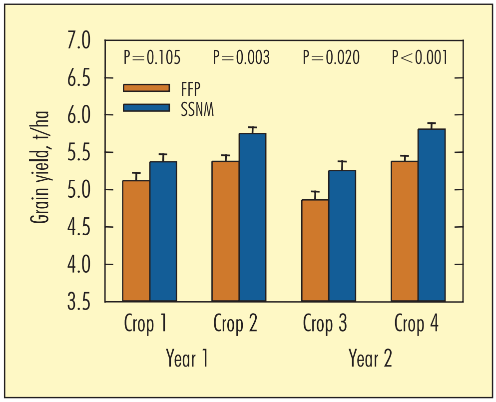


Figure 1. Grain yield (means, standard errors) in FFP and SSNM treatments, 1997-1999.

Results and Discussion

The average grain yield increase was 0.36 t/ha or 7 percent greater with SSNM compared to the FFP (**Figure 1**). Yield advantages with SSNM were similar in both high and low yielding seasons, and increased due to greater experience from 0.31 t/ha in the first year (+6 percent) to 0.41 t/ha in the second year (+8 percent). With the exception of the first crop, grain yields in SSNM plots were consistently higher compared with the FFP treatment. The probability of a yield increase was 73 percent, with no difference between high and low yielding seasons. Plant uptake of N, P, and K was greater with SSNM compared with FFP.

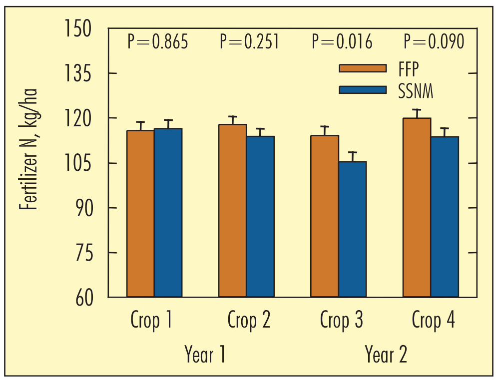


Figure 2. Fertilizer N use (means, standard errors) in FFP and SSNM treatments, 1997-1999.

The *total* amount of fertilizer N applied was initially similar in the two treatments, but N rates were about 7 percent lower in SSNM in the second year (crops 3 and 4, **Figure 2**). Fertilizer N management in SSNM and FFP differed mainly in terms of the splitting and timing of N fertilizer. Fertilizer N was applied more frequently in SSNM with an average of 3.1 applications per crop in SSNM compared to 2.6 in FFP (most farmers applied fertilizer N early in the season, when the capacity for efficient N recovery is small). Under SSNM, N applications were typically delayed by five to six days compared to FFP and the average fertilizer N split in SSNM was about 10 kg N/ha or 25 percent less than in FFP.

Fertilizer P and K rates in SSNM were adjusted over the four seasons. Application rates were reduced in the second season as more data from nutrient omission plots became available to fine-tune the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model. Differences among treatments in fertilizer P rates were generally small and decreased over the four crops (**Figure 3**). Fertilizer K rates predicted by the model to achieve target yields and maintain the soil indigenous K supply were, on average, higher than the amounts

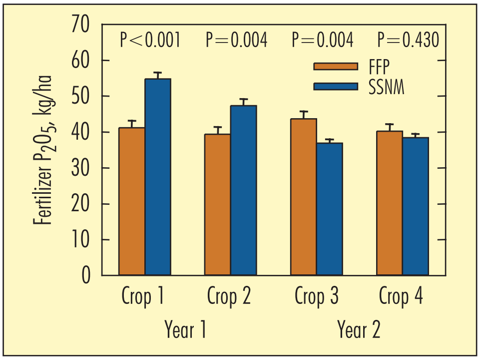


Figure 3. Fertilizer P_2O_5 use (means, standard errors) in FFP and SSNM treatments, 1997-1999.

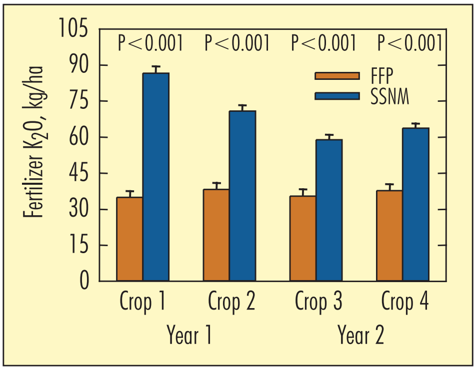


Figure 4. Fertilizer K_2O use (means, standard errors) in FFP and SSNM treatments, 1997-1999.

currently applied by farmers (**Figure 4**). Potassium rates in SSNM were adjusted from 79 kg K_2O/ha/crop in the first year to 61 kg K_2O/ha/crop in the second year, while the average farmer fertilizer K_2O rate remained unchanged at about 37 kg K_2O/ha/crop.

Recovery efficiency of fertilizer N increased significantly with SSNM (**Table 3**). On average, REN increased by about 29 percent with SSNM (40 percent) compared to FFP (31 percent). There was no difference among treatments in PEN, indicating that plants in both treatments transformed fertilizer N into grain yield with equal efficiency (PEN about 36 kg/kg). Agronomic N use efficiency was greater with SSNM (14.8 kg grain/kg fertilizer N) than FFP (11.5 kg grain/kg fertilizer N) due to greater REN in the SSNM treatment. The improved synchrony between plant N demand and supply from soil and fertilizer was probably the main cause of increased uptake of N, P, and K and the observed yield increase in SSNM.

Internal N efficiency in SSNM reached 57 kg grain produced per kg plant N uptake (**Table 3**), which is 85 percent of the theoretical optimum of 67 kg/kg that can be achieved with optimal crop and nutrient management (Witt et al., 1999). The conversion rate of nutrient uptake to grain yield was similar for P and K, and the difference between SSNM and FFP treatments was small. This suggests that the occurrence of stress factors other than nutrient supply was probably similar in the two treatments and that there is potential to further increase yield at the same level of nutrient uptake. More detailed analysis indicated that while nutrient uptake was sufficient to achieve the yield goal (set at almost 80 percent of the yield potential), actual yields in SSNM were about 67 percent of the po-

Table 3. Effect of SSNM on N use efficiencies in 179 irrigated rice fields of Asia (four crops in 1997 to1999).

		Treatment			
	Levels[a]	SSNM	FFP	Δ[b]	P>|t|[b]
Internal efficiency,	All	56.9	58.6	-1.7	0.004
(IEN, kg grain/kg	HYS	57.5	59.0	-1.5	0.070
plant N)	LYS	56.2	58.2	-2.0	0.025
Agronomic efficiency,	All	14.8	11.5	3.3	<0.001
(AEN, Δkg grain/kg	HYS	16.2	12.7	3.5	<0.001
fertilizer N)	LYS	13.4	10.3	3.1	<0.001
Recovery efficiency,	All	0.40	0.31	0.09	<0.001
(REN, Δkg plant N/kg	HYS	0.44	0.36	0.08	<0.001
fertilizer N)	LYS	0.37	0.28	0.09	<0.001
Physiological efficiency,	All	37.2	36.3	0.9	0.320
(PEN, Δkg grain/Δkg	HYS	37.6	36.1	1.5	0.226
plant N)	LYS	36.9	36.6	0.3	0.809

[a] All - four crops; HYS – High yielding season; LYS – Low yielding season.
[b] Δ is the difference between SSNM and FFP; P>|t| - probability of a significant mean difference between SSNM and FFP.

tential yield compared to 62 percent in FFP. It is likely that further yield increases will only be achieved if other crop management factors are also improved.

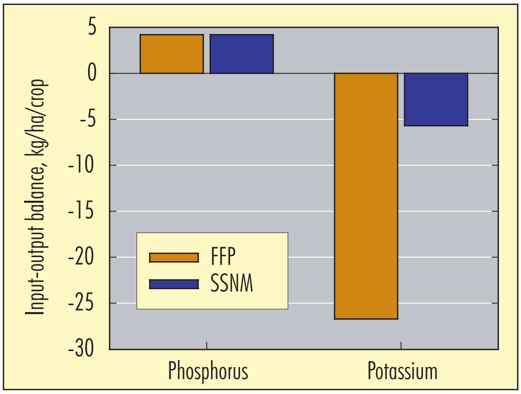
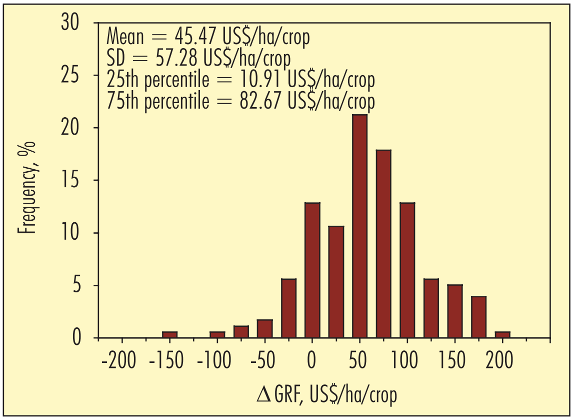


Figure 5. Estimated average input-output balance of phosphorus and potassium in FFP and SSNM treatments after four consecutive crops, 1997-1999.

Nutrient balances were constructed for P and K, based on fertilizer inputs and nutrient removal with grain and straw, for the four crops grown between 1997-1999 (**Figure 5**). The average input-output balance for P was positive in 75 percent of all farms and averaged less than 5 kg P/ha/crop. There were no differences between SSNM and FFP and this suggests that the average fertilizer P use of about 40 kg P_2O_5/ha/crop appears to be sufficient to support current average yields and sustain a small positive P balance in the soil in most farms. The average K balance, however, was negative in FFP because insufficient fertilizer K was applied to replace the amount removed in the crop and straw. Potassium balances were negative on 80 percent of all farms and averaged about -25 kg K/ha/crop. The negative K balance was reversed with SSNM in many farms, and site-specific K management reduced the average K balance to about -5 kg K/ha/crop.

When averaged over four crops and all sites, financial profitability of rice farming in SSNM was increased by about US$45/ha/crop compared with FFP (**Figure 6**). Average net return (total revenue minus total costs) was estimated at about US$400/ha/crop; SSNM increased net returns by about 12 percent. Site-specific nutrient management was profitable for almost 80 percent of farmers when averaged over four cropping seasons. There were substantial differences in profitability among sites. Good general crop care is needed to realize the full benefits of improved nutrient management strategies.

Figure 6. Farm-specific financial profitability of SSNM over FFP (increase in gross return over fertilizer cost due to SSNM, ΔGRF), average of four crops, 1997-1999



Conclusions

Field-specific management of macronutrients increased yield by seven percent and profitability by 12 percent on 179 rice farms in Asia. Increased nutrient uptake and N use efficiency across a wide range of rice growing environments with diverse climatic conditions were related to the effects of improved N management and balanced nutrition. A major challenge is to simplify the approach for wider scale dissemination without sacrificing components that are crucial to its success. The underlying principles of SSNM need to be carefully identified and evaluated for each macronutrient. Approaches to further dissemination must be related to prevailing site-specific conditions.

A limited number of well-positioned nutrient omission plots in a particular domain provide sufficient information on soil nutrient supplies to develop improved nutrient management strategies, particularly for the less limiting nutrients, P and K. The many theoretical and technical limitations of soil-test based approaches may therefore be overcome by simple and robust plant-based indicators of nutrient supply such as grain yield in omission plots and leaf color. Leaf color charts can be used as an on-farm guide for N management, since field-specific decisions for N management are probably required to achieve the best match between highly variable plant N demand and fertilizer N application. Results suggest that further increases in yield can only be expected when the farmer exploits the synergy that occurs when *all* aspects of crop, nutrient, and pest management are improved simultaneously. However, this sample of farmers achieved relatively high average rice yields representative for the intensive, irrigated lowland conditions in which future yield increases are likely to be achieved only in smaller increments. **BCI**

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