Variation in the Performance of Site-Specific Nutrient Management among Different Environments with Irrigated Rice in Asia

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Geographical differences in the performance of a new site-specific nutrient management (SSNM) approach were evaluated for major rice growing environments in six Asian countries. Four major cropping scenarios and corresponding nutrient management strategies are discussed using the experimental sites as examples.

The generic SSNM approach (Witt and Dobermann, 2002) evolved gradually to include location-specific adjustments according to variety, crop establishment method, application of organic fertilizer sources, and water management. Compared to farmer fertilizer practice (FFP), overall average yields with SSNM increased by 7% and profitability by 12% (Dobermann et al., 2002a). However, there were considerable geographical differences in the agronomic and economic performance of SSNM. This was not unexpected as the data set covered diverse cropping conditions with differences in climate, varieties, crop establishment methods, fertilizer use, labor input, and other factors.

There is evidence that climate had a large affect on the overall variation in yield between sites, years, and seasons, particularly since the experimental period included the El Niño – La Niña climatic cycle. However, SSNM performed well across a wide range of conditions, suggesting that the method is sufficiently robust. In this article, we evaluate geographical differences in the performance of SSNM by grouping the experimental sites according to nutrient management recommendations or characteristic constraints. Experimental approach, treatments, and performance indicators for the data set have been described in Parts 1 and 2 of this series, and Dobermann et al., 2002a and 2002b.

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.

Reductions in Fertilizer Use

Fertilizer use can be reduced at sites where the difference between nutrient requirement for a targeted yield goal and the indigenous nutrient supply is small. The most overused macronutrient in this study was nitrogen (N), as shown in **Table 1.** With SSNM, fertilizer N rates were reduced significantly, by 10 to 20% at the experimental sites in China (JI), Vietnam (HA and OM), and Indonesia (SU).

Fertilizer N, phosphorus (P) and/or potassium (K) were reduced substantially at sites with transplanted rice near Hanoi in the Red River Delta of North Vietnam (HA), at Jinhua (JI) in Zhejiang province, China, and at Suphan Buri (SB), Thailand. Several factors are common to both sites, including sub-tropical climate, a double-rice based cropping system, high indigenous soil fertility status (**Table 2**), use of large amounts of mineral fertilizer in FFP (**Table 1**), and very small farm sizes (0.3 ha).

Table 1. Fertilizer use with SSNM at eight sites in Asia (average of four crops, 1997 to1999).

Site	Fertilizer N SSNM	Δ^1	Fertilizer P_2O_5 SSNM	Δ	Fertilizer K_2O SSNM	Δ
	kg/ha					
JI	133	-35	34	-9	72	6
HA	93	-11	37	-9	64	-11
AD	127	15	60	4	84	38
TH	129	34	41	4	96	54
MA	111	1	44	9	59	32
OM	98	-13	50	7	75	50
SB	111	2	41	-7	54	52
SU	103	-21	44	25	64	59
All	112	-5	44	2	70	34

[1] Δ is the difference between SSNM and FFP.

Compared to the FFP, nutrient management in SSNM on the 45 farms at these sites was characterized by:

- a reduction in the use of fertilizer N (10 to 20%), P (20%), and K (15% only in HA,**Table 1**);
- large relative increases in N use efficiencies, including agronomic N use efficiency (AEN), physiological N use efficiency (PEN), and recovery efficiency of fertilizer N (REN), due to plant-based N management (**Table 3**);
- high internal N efficiencies (IEN) close to the optimum of 67 kg grain/kg plant N (Witt et al., 1999), indicating well balanced nutrition and absence of other stress factors [(**Table 3**) (Also see Part 2 of this series)];
- high average rice yields of 6.2 to 6.4 t/ha (**Table 4**), and
- high achievement of the yield goal (about 80 to 95 percent, **Table 4**).

Table 2. Potential soil nutrient supply measured as grain yield in nutrient omission plots.[1]

Site	N	P	K
	Grain yield, t/ha		
JI	5.6	6.9	6.8
HA	5.0	6.3	6.0
AD	5.0	6.7	6.7
TH	4.3	6.0	5.8
MA	4.4	6.1	6.1
OM	3.6	3.9	4.3
SB	4.4	4.2	4.1
SU	3.9	4.9	5.0
All	4.5	5.6	5.6

[1] Two highest values out of four seasons, 1997 to1999.

At site HA, yield increases over FFP were small, probably because yields were already close to 80% of the yield potential (Witt and Dobermann, 2002). Nevertheless, the profitability of SSNM was acceptable (**Figure 1**) at this site because of excellent crop management (finely tuned NPK fertilizer management) and reduced fertilizer costs.

The large yield and profitability increases with SSNM at site JI were mainly related to improved N management (three to

Table 3. Nitrogen use efficiencies with SSNM (average of four crops, 1997-1999).

Site	IEN SSNM	Δ^1	AEN SSNM	Δ	PEN SSNM	Δ	REN SSNM	Δ
	kg/kg							
JI	61	3.1	11	5.0	40	3.1	0.29	0.11
HA	66	-0.4	18	4.0	46	2.9	0.39	0.06
AD	63	0.5	16	2.1	35	2.2	0.43	0.04
TH	58	0.0	15	1.4	31	3.1	0.46	0.01
MA	50	-0.8	15	3.0	34	-2.9	0.46	0.14
OM	58	-4.8	20	5.0	46	0.8	0.44	0.10
SB	53	-1.9	9	1.6	33	-2.9	0.29	0.07
SU	44	-4.1	13	3.8	29	-0.1	0.46	0.15
All	57	-1.7	15	3.3	37	0.9	0.40	0.09

[1] Δ is the difference between SSNM and FFP.

Table 4. Average yield goal, grain yield, and achievement of goal with SSNM (average of four crops, 1997 to 1999).

Site	Yield goal	Grain yield	Grain yield	Achievement of yield goal, %
	---------t/ha---------			
	SSNM	SSNM	Δ[1]	SSNM
JI	7.83	6.35	0.45	81
HA	6.60	6.24	0.19	95
AD	7.74	6.45	0.49	83
TH	7.23	5.64	0.63	78
MA	7.17	5.26	0.51	73
OM	6.22	4.77	0.33	77
SB	6.02	4.90	0.10	81
SU	6.31	4.52	0.22	72
All	6.90	5.54	0.36	80

[1]Δ is the difference between SSNM and FFP.

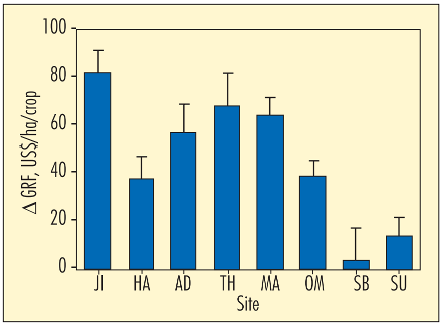
four fertilizer N applications compared to farmer practice where all fertilizer N is applied within the first 10 days after crop establishment). However, the N recovery efficiency was only moderate with SSNM (0.29 kg/kg, **Table 3**), suggesting potential for further improvement in N management.

Increasing Fertilizer Use

The SSNM concept suggests increased fertilizer use if the analysis of soil nutrient supply, yield potential, and current yield indicate a sufficiently large yield gap that cannot be exploited adequately at current fertilizer levels. The most frequently increased macronutrient was K. Except for the two sites in JI and HA, fertilizer K rates with SSNM were 32 to 59 kg K_2O/ha greater than commonly applied by farmers, and K balance calculations showed that these rates were required to replenish the amount of K removed with grain and straw. However, improved models are required to better address the long-term effects of both fertilizer P and K application considering other crop management practices (Witt et al., this issue).

Results are summarized from two sites where fertilizer K rates as well as fertilizer N and/or P rates were increased substantially with SSNM. This group included sites with transplanted rice in the old (AD) and new (TH) Cauvery Deltas of Tamil Nadu, India. Many factors are common to both sites, including tropical climate, a double rice-based cropping system, medium size fields (0.5 to 1 ha), high soil fertility (AD greater than TH, **Table 2**), relatively balanced fertilizer NPK rates in FFP including 42 to 46 kg K_2O/ha, moderate to high N use efficiencies in FFP, and moderate to excellent quality of crop management. At both sites, labor input is high (80 to 150 man days/ha), and pesticide use is low. Hand weeding is the primary weed control method and farmers attempt to follow integrated pest management (IPM) guidelines for insect pest control.

Figure 1. Financial profitability of SSNM over FFP (means, standard errors) for each site, average of four crops, 1997-99 (ΔGRF= increase in gross return over fertilizer cost due to SSNM).



Compared to FFP, SSNM in the 40 farms at these sites was characterized by: increases in fertilizer N (12 to 36%), P (8 to 13%), and K (>100%); little change in the already quite high N use efficiencies (**Table 3**); large average rice yields in the SSNM (5.6 to 6.4 t/ha) and large yield increases over FFP (**Table 4**); a moderate achievement of the yield goal (78 to 83%, **Table 4**); and large increase in profitability (**Figure 1**).

Increased N uptake (13 to 22%) was probably the major cause of yield increases at both sites. Targeted yield goals were higher at AD than TH because of the differences in soil fertility between the two areas (**Table 2**). Fertilizer NPK rates and the relative yield gain was similar at both sites, indicating that soil fertility needs to be considered in the yield goal selection. Given the lower soil fertility in TH, it would probably be difficult to achieve the high yield levels that were reached in AD. Insect pests mainly caused yield losses observed at AD, and there were indications of more stress (water supply, insects) at TH.

Exploiting the Synergy of Improved Nutrient and Crop Management

At all sites, there is a great potential to improve fertilizer N management through strategies that focus on plant N needs. Depending on the site, this may require adjustments in fertilizer NPK use, but also greater crop care to fully exploit the potential of improved nutrient management strategies. This diverse group included sites in Central Luzon (MA), Central Thailand (SB), and the Mekong Delta (OM). These factors are common to all sites: tropical climate; two (MA) or two to three annual rice crops (SB, OM); small to medium size fields (less than 0.5 to 1 ha); broadcast, direct-seeded rice with high seed rates (100 to 200 kg/ha); poor soil nutrient supply (except for MA, **Table 2**); small inputs of fertilizer K in FFP (2 to 26 kg K_2O/ha, **Table 1**); and relatively small amount of labor used (15 to 60 man days/ha). Pesticide use varies, but farmers generally use herbicides for weed-control. Straw is usually burned in the field.

Compared to FFP, the performance of SSNM on the 74 rice farms at these sites was characterized by: large increases in the use of K fertilizer compared to the FFP (**Table 1**); small to large increases in N use efficiency (**Table 3**); internal N efficiencies below the optimum of 67 kg grain/kg plant N (**Table 3**); low to moderate average rice yields of 4.8 to 5.3 t/ha and wide variation in the yield increase over FFP (**Table 4**); low grain filling percentage of about 75%; and widely varying quality of crop management.

Differences in profitability among sites (**Figure 1**) were largely caused by differences in the yield increase achieved with SSNM (**Table 4**). A more detailed analysis indicated that the nutrient uptake was sufficient to achieve higher yields, but poor grain filling at all three sites indicated that yield losses were mainly caused by stress during the reproductive growth phase. Unfavorable climate, water management, poor seed quality, weeds, insect pests, and diseases were common problems in these direct-seeded rice areas, particularly in wet season crops. These constraints often reduced yields and profitability regardless of fertilizer strategies. Special crop care is not required for SSNM to be profitable at sites where nutrient and non-nutrient related constraints are equally

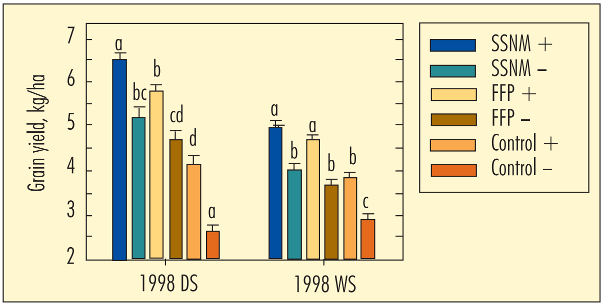


Figure 2. Grain yield (means, standard errors) on 27 farms with SSNM, FFP, and an unfertilized control in Maligaya (MA), Cental Luzon, Philippines, 1998 DS and WS. Farms were grouped according crop management problems (+ little or no problems; – severe problems).*

*Values with the same letter in a column are not statistically different at the 5% probability level.

limiting to yield, such as Maligaya, Philippines (**Figure 2**). Yield differences of up to 2 t/ha were observed in the dry season (DS) vs. the wet season (WS), depending on nutrient management and the occurrence of other constraints such as poor seed quality, high planting density, weeds, diseases, and rats (SSNM+ vs. FFP–). Greater crop care and integrated approaches that improve both pest and crop management would certainly be required to fully exploit the potential of improved nutrient management.

Constraints Other Than Nutrient Management

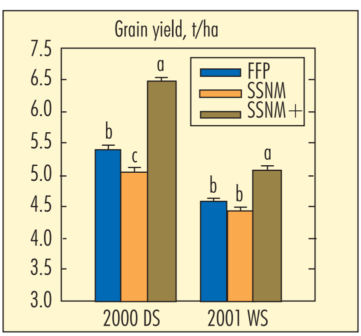
Field observations and the evaluation of N use efficiencies indicated that constraints other than nutrient supply were the major reason for only small yield increases with SSNM at the experimental site in Sukamandi (SU), West Java, Indonesia.

This site is characterized by: tropical climate; a double-rice cropping system with transplanted rice; moderate soil nutrient supply (**Table 2**); and small field sizes (less than 0.5 ha).

Average yields in FFP and SSNM were the lowest among all sites (4.3 t/ha), and yield goals were rarely achieved with SSNM (**Table 4**). Although plant-based N management with SSNM increased the recovery of applied fertilizer N by 50%, the extra N taken up by the crop was not converted into grain yield (**Table 3**). With only 44 kg grain/kg plant N, internal efficiencies of N were the lowest among all sites. Similar results were obtained when calculating the internal efficiencies of P and K suggesting constraints other than nutrient supply. Several likely causes for low internal efficiencies were identified, including: unfavorable climatic conditions caused by the El Niño – La Niña cycle; abiotic and biotic stresses including water shortage, rats, weeds, and insects; and low planting density (14 hills/m^2).

An additional SSNM treatment was implemented for two seasons with a planting density of 21 hills/m^2 (SSNM+, **Figure 3**). Both SSNM treatments received about 80 kg fertilizer N/ha versus 120 kg N/ha in FFP. Results from this experiment showed that yield and profitability can be increased when improved crop management practices are introduced. Yields with SSNM+ were close to the yield goal of previous years and 16% greater than in FFP. The fertilizer cost was about US$40/ha in both SSNM and FFP, but the profitability (gross return over fertilizer cost) increased by US$130/ha with SSNM+ due to the increase in yield, and the increase is expected to be large enough to compensate for the increased labor cost in crop establishment.

Figure 3. Average grain yield (means, standard errors) on 20 farms with FFP and SSNM in Sukamandi (SU), Indonesia, 2000 DS and 2000/01 WS. Fertilizer management was the same in both SSNM treatments, but SSNM+ had a higher planting density compared to FFP and SSNM.*



Conclusions

The SSNM approach provides a strong conceptual framework for analyzing current cropping conditions and farmers' nutrient management practices and the identification of nutrient and non-nutrient related constraints to increased productivity. Results indicated that yields and profitability can be improved substantially through SSNM at six out of eight sites, although the complexity of the nutrient related constraints and the corresponding strategies differed greatly among the different sites. At some sites, rather crude adjustments to fertilizer management practices may be sufficient, while a greater degree of fine-tuning is required at others. In further validation of the technology, we hope to exploit the synergy that occurs when other aspects of management (including pest and/or certain aspects of crop management) are improved simultaneously. At present we are simplifying the technology for use by extension workers for wider scale dissemination. **BCI**

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