Balancing Fertilizer Use and Profit in Asia's Irrigated Rice Systems

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About 90% of Asia's population, particularly the most impoverished, depend on rice as a source of their calories. The production of sufficient rice in Asia at an affordable price for the poor relies on the effective use of fertilizers, especially in the irrigated lowlands that produce 75% of Asia's rice.

Increasing fuel and fertilizer prices raise concern about whether Asian rice farming can successfully maintain the delicate balance between sufficient profitability for farmers and sufficient rice supply at affordable prices for the urban and the non-farming rural poor. Rising prices for fertilizers could stimulate rice farmers and policy makers to examine existing use of fertilizer. Reductions in fertilizer use and adjustment in the relative use of fertilizer N, P, and K might appeal to farmers and policy makers as fertilizer prices increase. But, crop yield is directly related to amount of nutrient taken up by a crop. At some point, less fertilizer use means lower crop yield and less profit for farmers. How much fertilizer use is just right for high profit?

In this paper we provide principles that address critical agronomic and economic issues at the farm level as fertilizer prices increase. We aim for principles that assist farmers in decision making on nutrient and crop management to achieve high productivity and profitability at low risk while meeting acceptable standards of environmental quality.

Ensuring Profitable Fertilizer Use — N

Nitrogen is typically the nutrient most limiting rice yield and the nutrient needed in largest quantity from fertilizer. In Asia's irrigated rice systems, the naturally occurring (i.e., indigenous) supply of N from soil is typically sufficient to achieve a grain yield of 3 to 5 t/ha without application of fertilizer N (Dobermann et al., 2003), and even higher yields of 5 to 7 t/ha without fertilizer N can be achieved in irrigated areas of China (Peng et al., 2006). But across Asia, yields of irrigated rice in the absence of fertilizer N are consistently insufficient to meet food needs and achieve highest profit for farmers. Fertilizer N is clearly needed, but the optimal management of fertilizer N to match crop needs and achieve high profit is season and location specific, varying even among adjacent fields within the same season.

We present four scenarios to illustrate principles for ensuring profitable rice farming as the price of fertilizer N increases. The four scenarios increase progressively in intensity of required knowledge and in magnitude of potential benefits to rice farmers. In all scenarios we use the production function illustrated in **Figure 1a** to represent an existing situation in a farmer's field, and we use the following to assess the effect of a 50% increase in cost of fertilizer N:

- Farm gate price of unmilled (paddy) rice = US$0.31/kg
- Cost of fertilizer N: Standard = US$0.59/kg, the current non-subsidized price in Indonesia. Cost with 50% increase = US$0.87/kg

The increase in grain yield with incremental addition of fertilizer N is location and season specific, depending upon many factors including rice variety, climate, crop management, management and timing of fertilizer N, use of organic inputs, and the sufficiency of other essential nutrients. We, therefore, selected a generic response of rice to fertilizer N (**Figure 1a**). The grain yield of 3.5 t/ha without fertilizer N is near the average for irrigated areas outside China without input of manure (Dobermann et al., 2003). The maximum yield of 5.6 t/ha and the maximum increase in yield of 2.1 t/ha with fertilizer N reflect a response of intermediate magnitude for irrigated rice in Asia.

Topdressing N fertilizer to rice. (Photo courtesy of IRRI).

The increase in yield per unit of applied fertilizer N (i.e., agronomic efficiency of fertilizer N, AE_N) is a measure of the efficiency of fertilizer N use by the crop. The AE_N decreases with increasing fertilizer N (**Figure 1a**).

The gross return over fertilizer cost (GRF), which is the farm gate revenue from produced rice minus cost for fertilizer N applied, provides a relative measure among scenarios for the benefit derived by farmers from the use of fertilizer N. The GRF is largest at the point of profit maximization in the production function, which occurs at a fertilizer N rate slightly less than the maximum yield. In **Figure 1a**, profit maximization with standard fertilizer N cost occurs with use of 138 kg N/ha to achieve a yield of 5.6 t/ha with AE_N = 15 kg/kg (**Table 1**). An AE_N near 15 kg increase in grain per kg N applied is common with existing management practices for irrigated rice in Asia. Although markedly lower AE_N (<10 kg/kg) is widespread in China as a result of high fertilizer N use relative to the increase in yield from N fertilization (Peng et al., 2006).

Fertilizer represents only a fraction of total input costs in rice farming. In a 1999 study across seven irrigated rice areas of Asia, fertilizer represented from 11 to 28% of total input

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium; Zn = zinc; IRRI = International Rice Research Institute.

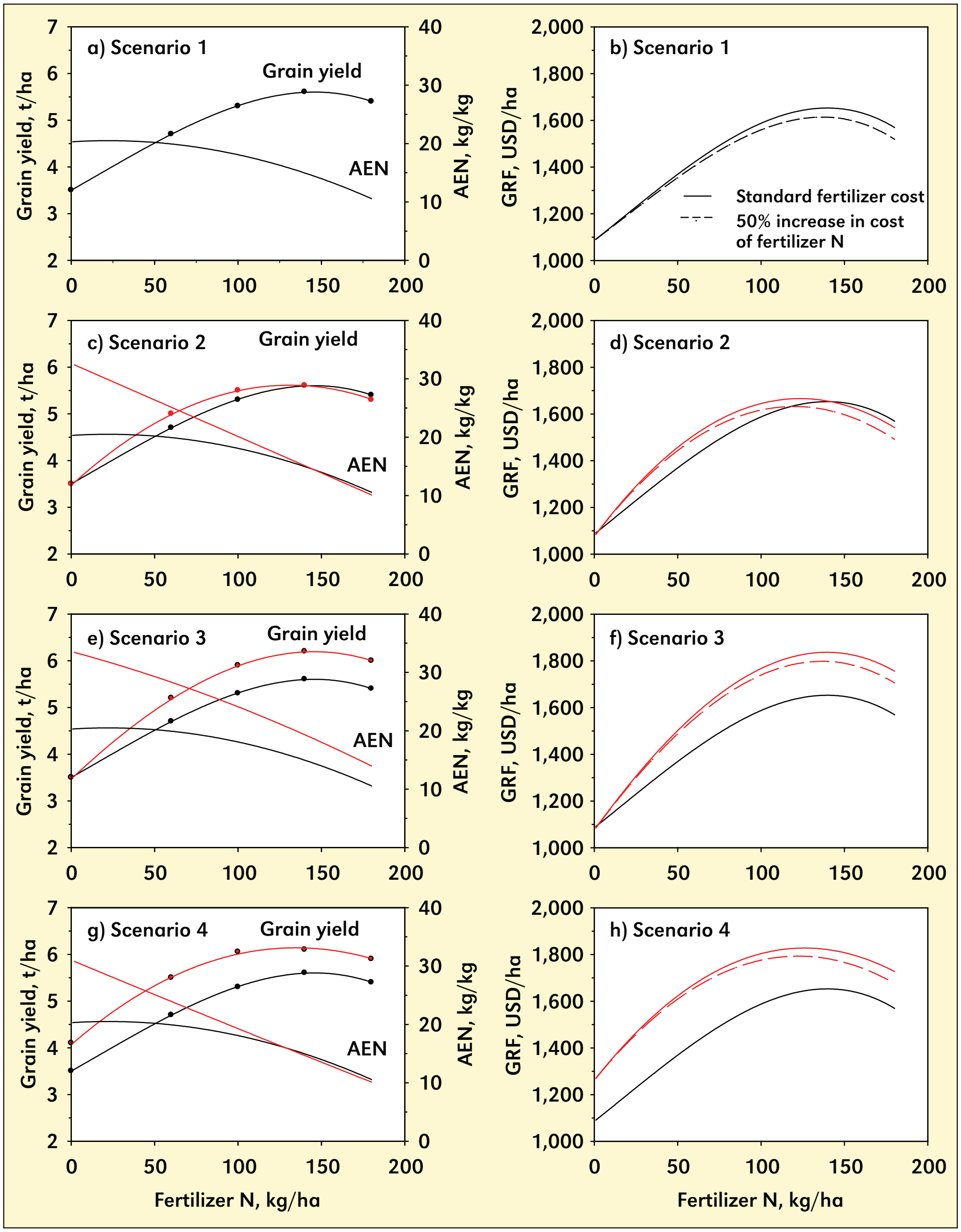

Figure 1. Example for a typical production function in a farmer field (a) and gross return over fertilizer cost (GRF, revenue minus cost for fertilizer N applied) for two fertilizer N costs (b). The red lines for production functions in (c), (e), and (g) represent different scenarios for changes in management (see text for further information), while the black line represents the function in farmer field (a). Figures (d), (f), and (h) represent the GRF for the respective scenarios, at two fertilizer N costs, relative to the typical production function at standard fertilizer N cost in (b). AE_N = agronomic efficiency of fertilizer N.

cost (Moya et al., 2004), and fertilizer N would represent only a portion of this total fertilizer cost. The net benefit of rice farming would be markedly less than GRF because GRF does not consider costs other than fertilizer N; but GRF provides a valuable measure of the relative differences in benefits between reported scenarios and fertilizer N costs. In our analysis, we assume that labor requirements and input costs other than for fertilizer N do not alter with the changes in fertilizer and crop management required to achieve the production functions for Scenarios 2 to 4.

Scenario 1: Improving the pre-season estimate of required fertilizer N

In some areas of Asia the profitability of rice farming, even at existing fertilizer N prices, can be increased by simply adjusting the rate of fertilizer N with no other change in the existing management practices for fertilizer N and rice. Rice farmers and extension workers often underestimate indigenous N supply and the yield without fertilizer N (Y_0) in irrigated rice fields. The flooding of soils for production of rice enhances indigenous N supply and Y_0 through greater inputs of N via biological N_2 fixation and greater net release of plant-available soil N. An underestimation of Y_0 translates into an overestimation of crop response to fertilizer N (ΔY) and the requirement for fertilizer N. The ΔY in irrigated rice fields in Asia is often in the range of 1 to 2 t/ha. In favorable high-yielding seasons, ΔY can increase to 3 to 4 t/ha. In China despite relatively high yields of fertilized rice, ΔY is typically ≤2 t/ha and only periodically 3 t/ha (Peng et al., 2006; Wang et al., 2007).

The site-specific nutrient management (SSNM) as developed for rice in Asia (Dobermann et al., 2004; IRRI, 2007) can be used to quickly assess whether existing fertilizer N rates can be reduced to increase profit. The first step is to estimate through best available information whether the anticipated response of rice to fertilizer N with existing crop management practices (ΔY) approximates 1, 2, 3, or 4 t/ha. If farmers currently use >80 kg fertilizer N per each ton of increased paddy yield from fertilizer N (AE_N<12 kg/kg), then the fertilizer N rate can likely be decreased with no loss in yield.

Farmers should ideally fertilize to achieve the yield where GRF is maximum—the point of profit maximization. In the case of the production function illustrated in **Figure 1a**, the yield

Table 1. Yield, fertilizer N, and fertilizer N efficiencies at two fertilizer N costs for scenarios 1, 2, 3, and 4 of Figure 1 as described in the text. GRF = Gross return over fertilizer cost

Parameter		Unit	Scenario 1	2	3	4
Grain yield, without N	Y_0	t/ha	3.5	3.5	3.5	4.1
Grain yield, maximum	Y_M	t/ha	5.6	5.6	6.2	6.1
N rate, at Y_M	N_M	kg/ha	145	129	144	132
Standard fertilizer N cost						
Grain yield, at maximum GRF	Y	t/ha	5.6	5.6	6.2	6.1
Fertilizer N, at maximum GRF	F_N	kg/ha	138	120	136	122
Agronomic efficiency of N, at maximum GRF	AE_N	kg/kg	15	17	20	17
Change in net benefit at maximum GRF in scenarios 2, 3, and 4 relative to scenario 1	ΔGRF	US$/ha	–	+10	+180	+170
50% increase in fertilizer N cost						
Grain yield, at maximum GRF	Y	t/ha	5.6	5.6	6.2	6.1
Fertilizer N, at maximum GRF	F_N	kg/ha	133	114	132	116
Agronomic efficiency of N, at maximum GRF	AE_N	kg/kg	16	18	20	17
Change in net benefit at maximum GRF in scenarios 1, 2, 3, and 4 at increased fertilizer cost compared to farmers' practice (scenario 1) at current fertilizer price	ΔGRF_{50}	US$/ha	-40	-20	+140	+140

at maximum GRF is 5.6 t/ha, and ΔY fits into the category of 2 t/ha (5.6 – 3.5 t/ha). An estimated requirement for fertilizer N based AE_N=15 kg/kg, which is often achievable with farmers' crop and fertilizer N management, would be 130 kg N/ha (2 t/ha x 1000/15). The use of more than 160 kg N/ha (AE_N<12 kg/kg) in such a location would be a clear warning of excessive fertilizer N use.

An increase in fertilizer N cost with no change in the production function, other costs, and farm gate paddy price would decrease profit (**Figure 1b**). With 50% increase in fertilizer N cost, the N rate at maximum profit decreased slightly from 138 to 133 kg N/ha (**Table 1**). Net benefit decreased by 40 US$/ha with the increase in fertilizer N cost.

When current rates of fertilizer N are excessive, an optimization of fertilizer N use can compensate for increased fertilizer N cost. For example, if current fertilizer N use is 170 kg N/ha, a reduction to the optimal of 133 kg N/ha would match additional cost for a 50% increase in fertilizer N and avoid a loss in profit. But if current fertilizer N use was <165 kg N/ha, the cost savings from a reduction of fertilizer N use would not by itself negate the 50% rise in fertilizer N cost. In such case, a shift in the production function through improved management practices would be required to negate the additional cost of fertilizer N.

Scenario 2: Reducing fertilizer N use through improved management

Asian rice farmers typically do not manage fertilizer N most effectively. For example, the early application of fertilizer N within 2 weeks after rice establishment often exceeds crop needs leading to excess vegetative growth and increased susceptibility to diseases and some insect pests (Peng et al., 2006; Wang et al., 2007). For best effect, farmers should apply fertilizer N several times during the growing season to ensure that the N supply matches the crop need for N at the critical growth stages of active tillering and panicle initiation. The SSNM approach provides principles for effective N management, including use of the leaf color chart (LCC) to assess leaf N status and adjust fertilizer N applications to match the needs of the rice crop for N (IRRI, 2007, Witt et al., 2007).

An improvement in fertilizer N management can shift the production function to the left toward greater efficiency of N use as illustrated in **Figure 1c**. In this case the primary focus is reducing fertilizer N use to increase profit. This represents situations where existing fertilizer N use, even when greater than optimal, has resulted in yield that cannot be increased further solely by improvements in N management.

"Reduce fertilizer N to increase profit" can at first glance seem an appealing message for farmers. Opportunities typically exist for farmers to further improve the distribution of fertilizer N to better match the crop needs for supplemental N. But farmers using fertilizer N near or above the rate for maximum GRF, derive little or no benefit from a savings in fertilizer N through improved N management without an accompanying increase in yield at maximum GRF (**Figure 1d**). Net benefit with Scenario 2 was only US$10/ha at the standard fertilizer N cost (**Table 1**).

When fertilizer N cost was 50% higher, the fertilizer N rate at maximum GRF decreased from 133 kg/ha in Scenario 1 to 114 kg/ha in Scenario 2 (**Table 1**). The savings in fertilizer N associated with Scenario 2, however, failed to compensate for the added costs associated with the 50% increase in fertilizer N cost (**Figure 1d**). There was a net loss of US$20/ha relative to the typical production function (Scenario 1) at standard fertilizer N cost.

The AE_N at maximum GRF in Scenario 2 was 17 kg/kg at standard fertilizer cost and 18 kg/kg with increased fertilizer N cost (**Table 1**). Based on research across Asia, an AE_N of 18 kg/kg in low-yielding seasons and 20 kg/kg or more in high-yielding seasons can be achieved with good N management including within season N adjustments using the LCC.

The greatest benefit from improved N management through a shift in the production function (Scenario 2) occurs for farmers using suboptimal rates of fertilizer N. Grain yields in Scenario 2 are markedly greater than grain yields for the typical production function at suboptimal N rates from 30 to 90 kg N/ha (**Figure 1c**). This translates into markedly higher GRF, and correspondingly higher net benefit, for Scenario 2 regardless of fertilizer N cost (**Figure 1d**).

With Scenario 2, farmers using suboptimal rates of fertilizer N could increase profit by increasing fertilizer N use despite a 50% increase in fertilizer N cost. For example, increasing N rate from 80 kg N/ha with existing management practices to the rate at maximum GRF (114 kg N/ha) with improved N management in Scenario 2 would increase net benefit by

Leaf color chart can be used to assess leaf N status and help adjust fertilizer applications. (Photo courtesy of IRRI.)

US$110/ha when fertilizer N cost increased by 50%. However, such suboptimal fertilizer N use is markedly less common for irrigated Asian rice farmers than the use of fertilizer N near or above the rate for maximum GRF.

Scenario 3: Increasing yield through improved management

An improvement in fertilizer N management can in some cases increase the maximum attainable yield, resulting in an upward shift in the production function as illustrated in **Figure 1e**; but an appreciable upward shift of the production function is most likely when improved fertilizer N management is accompanied by improved management to alleviate a major yield-limiting constraint such as insufficient supply of other nutrients (Alam et al., 2006). In this case, the primary focus is on overcoming yield-limiting constraints in order to increase profit through higher production rather than through an adjustment in input use per se. This scenario is most feasible where yield is constrained by a readily identifiable and easily alleviated limitation.

Scenario 3 illustrates an upward shift in the production function of 0.6 t/ha to 6.2 t/ha at maximum GRF (**Figure 1e, Table 1**). This substantially increases GRF relative to the typical production function in Scenario 1 (**Figure 1f**). The net benefit at maximum GRF was US$180/ha with standard fertilizer N cost (**Table 1**).

When fertilizer N cost was 50% higher, GRF remained higher with Scenario 3 than the typical production function with standard fertilizer N cost (**Figure 1f**). Scenario 3 is consequently financially attractive even with increased fertilizer cost, regardless of the farmer's current fertilizer N use. The fertilizer N rate at maximum GRF was little affected by the upward shift in the production function (Scenario 3 compared to Scenario 1 in **Table 1**). At increased fertilizer cost, the net benefit at maximum GRF was US$140/ha relative to the typical production function at standard fertilizer N cost.

Our experiences across Asia through multiple partnerships within the Irrigated Rice Research Consortium suggest such a large yield increase of 0.6 t/ha at maximum GRF in Scenario 3 would typically not be derived solely by improved management of fertilizer N. It would likely require combining another improved practice with improved N management. For example, the use of a better adapted rice variety, such as with better resistance to local pests and disease or with higher yield potential, could contribute to an upward shift in an existing production function. The intensification of cropping on Asian rice lands with sufficient fertilizer N for relatively high yield has increased the extraction of other nutrients from soil. Zinc, K, and S are increasingly being recognized in major rice-growing areas as important constraints to achieving higher rice yields as fertilizer N management is optimized.

"Increase yield to increase profit" (Scenario 3) can be a much more effective message for farmers than "reduce fertilizer N to increase profit" (Scenario 2). The markedly greater benefit derived from Scenario 3 than Scenario 2 suggests research, extension, and farmers should focus on identifying and overcoming the main field-level constraint to higher yield once N is eliminated as a constraint through profitable N management following SSNM principles (IRRI, 2007; Witt et al., 2007). Our analysis does not consider added costs associated with additional inputs to eliminate the yield-limited constraints. The profits for farmers would obviously depend on added costs, but our analysis clearly shows the markedly greater opportunity with Scenario 3 than Scenario 2.

Scenario 4: Improving use of indigenous N and increasing yield through improved management

In some cases the improvements in management can increase yield in the absence of fertilizer N as well as across all rates of fertilizer N, resulting in an upward shift in the production function as illustrated in **Figure 1g**. This scenario is comparable to Scenario 3, except there is an additional focus on improving management to achieve higher grain yield from the indigenous supply of N. This could include practices that enable either more effective extraction of N from soil or more effective conversion of extracted soil N into grain yield.

The establishment of rice by broadcasting germinated seed on wet soil has gained popularity as a labor saving alternative to manual transplanting. In many instances, Asian farmers, who practice wet seeding, use high seed rates in order to reduce risk and control weeds. This leads to excessive vegetative growth and a relatively low percentage of panicle-bearing tillers. In such a case the optimization of seed rate might increase yield in the absence of fertilizer N and across all rates of fertilizer N.

In the given example, maximum grain yield and net benefit at standard and increased fertilizer N costs relative to Scenario 1 were comparable for Scenario 4 and Scenario 3 (**Table 1**). The adoption of management practices to increase grain yield is vital for high profitability near maximum GRF even with increasing fertilizer cost because irrigated rice farmers in Asia often use fertilizer N near or above the rate for maximum GRF.

Fertilizer Cost and Profit – P and K

The needs of rice for P and K are directly related to grain yield. For each ton of grain yield, a mature crop of modern high-yielding rice typically contains the equivalent of about 6 kg P_2O_5 within its biomass. Hence, a 6 t/ha crop contains plant P equivalent to about 36 kg P_2O_5 at maturity. Two-thirds of this P is in the grain. Therefore, about 4 to 6 kg P_2O_5 are removed per hectare from a rice field for each ton of grain yield, depending on the amount of crop residue retained.

As a general principle, irrigated rice requires about 4 to 5 kg P_2O_5/ha from fertilizer — depending on the amount of straw retained — for each ton of grain yield to balance P removal. A rate of 4 to 5 kg P_2O_5/ha per ton of anticipated grain yield can serve as a general guideline for the essential fertilizer P requirement to maintain soil fertility and achieve high profit for irrigated rice with a history of fertilizer P use (Witt et al., 2007).

The need for fertilizer K depends upon the management of rice straw — which contains 80 to 85% of the K in a rice crop. It also depends on K contained in irrigation water and the K-supplying capacity of the soil, which are typically not known by farmers. Asian rice farmers are often not applying sufficient fertilizer K to balance the K removed in harvested grain and straw. The production of rice consequently relies on the extraction and depletion of K from soil reserves.

As illustrated through Scenarios 3 and 4 in **Figure 1**, further increases in yield are critical to ensuring and maintaining profitability for rice farming with increasing fertilizer costs. The adoption of improved N and crop management practices to increase rice yields will in many cases accelerate the depletion of soil K reserves. As a result, an insufficient supply to rice crops of K, and other nutrient such as Zn and S, could become increasingly important as a constraint to increased yield and profitability for rice farming. If supplies of fertilizer K become inadequate in a country to meet farmer needs, then scientists have an opportunity to provide guidelines, drawing upon SSNM principles, for distributing fertilizer K to achieve greatest yield gains per unit of fertilizer.

The SSNM approach fortunately provides principles to assess nutrient needs and techniques to guide the evaluation and improvement of current practices. Farmers for example can use simple field plot techniques provided through the SSNM approach to assess whether their current fertilizer K use is adequate for high profit and to tailor K fertilization to their field-specific needs (IRRI, 2007).

Conclusions

SSNM provides principles and guidelines for optimizing the rates and timing of fertilizer N at the field level. As fertilizer prices increase, increasing rice yield offers more opportunity than reducing fertilizer use per se to increase profit. Rice farmers should aim to combine improved N management with other management practices that increase profit by overcoming main yield-limiting constraints. As N management is optimized, it becomes increasingly important to rapidly identify and optimally manage other nutrients that become the main yield-limiting constraint. BC

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