A Site-Specific Nutrient Management Approach for Irrigated, Lowland Rice in Asia

By C. Witt and A. Dobermann

Site-specific nutrient management (SSNM) strategies that include site- and season-specific knowledge of crop nutrient requirements and indigenous nutrient supplies are required to increase productivity, yields, and nutrient use efficiency in irrigated rice systems of South and Southeast Asia. The SSNM concept described here was developed and tested in more than 200 farmer fields in six Asian countries.

By comparison with the large increases in yield that resulted from the introduction of green revolution technology in Asia, future yield and productivity increases in irrigated rice are likely to occur in smaller increments by fine-tuning nutrient and crop management. The SSNM approach was developed to increase mineral fertilizer use efficiency and achieve balanced plant nutrition (Dobermann and White, 1999; Witt et al., 1999; Dobermann and Fairhurst, 2000). Field- and season-specific fertilizer rates were calculated after taking into account indigenous soil nutrient supplies, plant nutrient demand (based on yield targets), and interactions among nitrogen (N), phosphorus (P), and potassium (K). This SSNM concept is valid for modern, high yielding varieties with a harvest index (ratio of grain to dry matter) of about 0.5.

A recommendation is provided for the total NPK fertilizer requirement depending on cropping season, crop establishment method, and inputs from other nutrient sources such as straw or manure. To improve the match between plant N requirements and fertilizer N supply, the SSNM strategy provides guidelines for splitting and timing fertilizer N applications according to crop growth stage. Nitrogen applications are fine-tuned during the season using a chlorophyll meter (SPAD) or leaf color chart (LCC) and when growing conditions in the season differ from the assumptions used in the N fertilizer recommendation model.

Field-specific fertilizer N, P, and K recommendations are calculated in five key steps.

Step 1: Yield goal selection

A yield goal is selected based on the variety-specific potential yield (Y_{max}), defined as the maximum possible grain yield limited only by climatic conditions when there are no other factors limiting crop growth.

Potential yield can be determined using crop simulation models or estimated from the highest yield recorded at a particular site in an experiment with near optimal conditions for crop growth. It is affected by crop management practices such as the crop establishment method and fluctuates among sites, farms, and years (typically ±10 percent) because of climatic variation, differences in genotypes, and variation in planting dates. In the sub-humid to humid subtropical and tropical regions of Asia, Y_{max} is normally 9 to 10 t/ha in high-yielding (usually dry) seasons and 6 to 8 t/ha in low-yielding (frequently wet) seasons when the amount of solar radiation is reduced due to greater cloud cover.

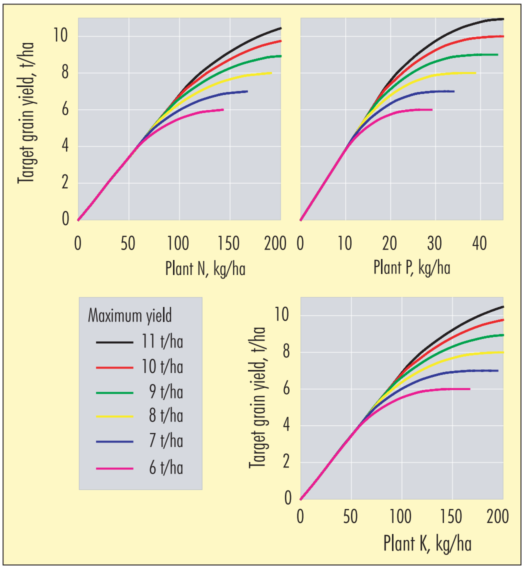
Season-specific yield goals are usually set to 70 to 80 percent of Y_{max} for several reasons:

- Internal nutrient use efficiencies decrease at very high yields near to Y_{max} (see Step 2).
- Practical experience has shown that the best farmers can achieve yields of about 80 percent of Y_{max} under normal field conditions.
- At a yield level of 70 to 80 percent Y_{max}, financial returns are greatest under open market conditions (i.e., where the difference between local and world market rice prices is small).

Step 2: Estimation of crop nutrient requirements

The nutrient uptake requirements of a crop depend on both yield goal and Y_{max}. Nutrient requirements in SSNM are estimated using the QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) model (Janssen et al., 1990), which we have adapted for rice (Witt et al., 1999). The model provides a generic approach for estimating crop nutrient requirements for a specified yield goal, taking into account the climate-adjusted, season-specific yield potential.

Figure 1. Relationship among maximum yield, target grain yield, and total nutrient uptake at harvest of rice.



Provided rice plant growth is limited solely by nutrient supply, the optimal nutritional balance is achieved with an uptake of about 15 kg N, 2.6 kg P, and 15 kg K per tonne of grain yield. These nutrient uptake rates are valid for yield goals that reach 70 to 80 percent of Y_{max} (**Figure 1**). Thereafter, the amount of nutrients required to produce an additional tonne of grain yield increases due to decreasing internal nutrient use efficiency.

Plant nutrient requirements for a particular yield goal may be smaller in a high yielding season than in a low yielding one. For example, 80 kg plant N would be required to support a yield goal of 5.5 t/ha at a Y_{max} of 10 t/ha, but 100 kg plant N would be required for the same yield goal at a Y_{max} of 6 t/ha (**Figure 1**). The model also provides a useful tool for identifying optimal yield goals based on the relationship between grain yield and nutrient uptake.

Nitrogen omission plot embedded in a farmer's field.

Step 3: Estimation of indigenous nutrient supplies

An important step in the calculation of site-specific fertilizer requirements is the estimation of the indigenous nutrient supply (INuS) of N, P, and K, defined as the total amount of a particular nutrient that is available to the crop from the soil during a cropping cycle, when other nutrients are non-limiting. The INuS is derived from soil, incorporated crop residues, water, and atmospheric deposition. It is estimated by measuring plant nutrient uptake in an omission plot (see photo). For example, the indigenous N supply can be measured as plant N uptake at harvest in a small 0-N plot (6 x 6 m) located in a farmer field, where P, K, and other nutrients are supplied in sufficient amounts so that plant growth is limited only by the indigenous N supply.

Using the plant as an indicator of soil nutrient supply has four major advantages. All sources of the particular nutrient available within the rooting zone are included in the assessment. It is possible to quantify crop management effects (e.g., length of fallow with soil aeration, tillage, and residue management) on soil indigenous nutrient supply. Farmers and extension workers cooperate together in farmer fields to determine indigenous soil nutrient supplies. Indigenous nutrient supply is measured in units that can be used directly in fertilizer calculations (kg nutrient per ha and crop).

A potential disadvantage is that the estimate is variety-specific (due to differences in root distribution, for example) and is affected by factors inherent in a particular variety that control nutrient uptake. To obtain reliable plant-based estimates of indigenous nutrient supplies using omission plots, the following points should be considered: use certified (treated) seed; manage the omission plot with proper crop care (water, weed, pest, and disease control); take measurements in a season with favorable climatic conditions and low pest pressure to minimize the effect of yield-limiting factors other than the nutrient under test.

Step 4: Calculation of fertilizer rates

Field-specific fertilizer N, P, and K recommendations are calculated based on the plant nutrient requirement for the selected grain yield goal (Steps 1 and 2), an estimate of the indigenous nutrient supply (Step 3), and the expected fertilizer recovery efficiency (RE, kg fertilizer nutrient taken up per kg applied) by the plant.

For example: Fertilizer N (kg/ha) = (UN – INuS) / REN, where UN is the plant N uptake requirement for the yield goal (kg/ha), INuS is the indigenous N supply measured as plant N uptake in a 0 N plot (kg/ha), and REN is the expected recovery efficiency of applied fertilizer N (kg/kg).

Before the SSNM strategy was tested in more than 200 farmer fields at six sites in Asia, first-crop recovery efficiencies for fertilizer N, P, and K were estimated in farmer fields within each recommendation domain using the difference method where the uptake of each nutrient is compared in fertilized and unfertilized omission plots. For all sites, values ranged from 40 to 60 percent for N, 20 to 30 percent for P, and 40 to 50 percent for K. Nitrogen recovery efficiency was assumed to be 50 percent when proper plant-based N management strategies are used (see Step 5). The recovery efficiency of N, P, and K applied with farm-yard manure was similar to values obtained for mineral fertilizer.

Instead of calculating fertilizer N, P, and K requirements individually and by hand, we used a linear optimization procedure in the QUEFTS model that takes into account interactions between nutrients to achieve an optimal nutritional balance. We also used season-specific upper limits for fertilizer rates (e.g., less than 180 kg N/ha in a dry-season) for the following reasons: to avoid excessive fertilizer N use; to work within fertilizer P and K rates that produce economic results; and to decrease the yield goal in cases where the model could not predict P and K rates satisfactorily for very low fertility status soils.

Low application rate limits were introduced for fertilizer P (23 kg P_2O_5/ha) and K (36 kg K_2O/ha) to ensure that removal from the field in crop products was replenished. All fertilizer P and 50 percent of fertilizer K were applied early in the season, and remaining K was applied at panicle initiation in line with farmer practice.

Step 5: Dynamic adjustment of fertilizer N applications

The total requirement for fertilizer N calculated in Step 4 provided a rough estimate of the amount of N required to reach the target yield under average climatic conditions in a particular season. Basic plans were then developed for splitting and timing N applications in relation to crop growth stages. Strategies differed from site to site depending on climatic season, variety and crop duration, crop establishment method, water management, and possible pest problems.

The strategy for N management evolved at each site as we gained experience. General principles include the following (Dobermann and Fairhurst, 2000):

- Decide on the requirement for pre-plant N application. Basal incorporation was generally carried out at sites where the planting density was low (e.g., hybrid rice in China) or at sites with relatively low early season soil temperatures (e.g., early rice, Red

River Delta, Vietnam). At all other sites, basal incorporation of N was only carried out where the indigenous N supply was less than 40 kg/ha in 0-N plots (i.e., yield less than 3 t/ha).

- Apply the remaining N fertilizer in two to three splits at critical growth stages, depending on plant growth and N requirement of a growth stage, season, growth duration, and variety.
- Apply a late season application of N to improve grain filling if the crop stand at that time is in good condition and there are few pest problems.
- Adjust the amount of each fertilizer N topdressing based on actual plant N status determined with SPAD (or LCC). Threshold levels were set for each crop establishment method. Guidelines on SPAD use evolved from a yes or no decision using single threshold levels to varying the amount of fertilizer N at critical growth stages based on a more continuous SPAD scale.

Conclusions

Fertilizer recommendations in Asia's irrigated lowland rice fields are presently too generalized and insufficiently related to the site-specific yield potential and local soil fertility status. In our approach, we use the total nutrient uptake required to reach a specified target yield, the soil nutrient supplying capacity measured in omission plots, and the plant recovery of fertilizer nutrients under local conditions to calculate site-specific fertilizer requirements. This approach does not require soil analysis and offers the advantage that agronomists, extension workers, and farmers work together in farmer fields to estimate fertilizer nutrient requirements. **BCI**

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