Optimizing Crop Nutrition

INTERNATIONAL POTASH INSTITUTE

# *e-ifc* No. 10, December 2006

Electronic International Fertilizer Correspondent (*e-ifc*). Quarterly correspondent from IPI.

## Editorial

Dear Readers,

Nutrient management of **Rice** is the scope of this edition of *e-ifc* No. 10. Grown on some 153 million ha it provides food for millions of consumers as well as income and livelihood to a myriad of farmers, most of them living in Asia. It is a story of success: Starting with a yield of 1.9 t/ha in 1961, it reached 2.7 t/ha in 1980 and these days can reach yields of 4 t/ha, demonstrating an increase in yield of almost one tonne every twenty years.

Without these yield increases the paddy area would have to be double of its present size to achieve the current output of nearly 600 million tonnes. In other words, increasing yields contributed substantially to safeguard of both the natural resources land and water.

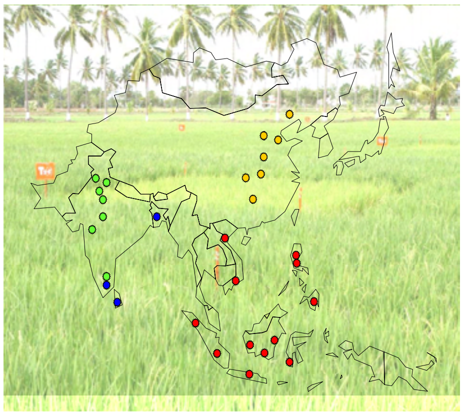
*Omission plot: The way to demonstrate response of a specific nutrient.*

I am extremely pleased to have received from scientists of the International Rice Research Institute, IRRI and from our regional office in Singapore a range of articles covering in eight chapters (see the Research findings of this edition) the following topics: ***(I)*** rice production and food supply in Asia, ***(II)*** concept and evaluation of ecological intensification of rice, ***(III)*** principles of site specific nutrient management (SSNM), ***(IV)*** practical fertilization recommendations for rice, ***(V)*** the need for potassium in fertilization of rice, ***(VI)*** description of a nutrient support system (NuDSS) for irrigated rice, ***(VII)*** a look at farmers' role in developing new fertilization strategies and finally ***(VIII)***, a description of the implications of nutrient requirements in rice towards 2020.

IPI started supporting research at IRRI on nutrient management in rice in 1998. In 2001, the 'RTOP' workgroup was established at IRRI with funds received from the Swiss Agency for Development and Cooperation (SDC), the International Fertilizer Association (IFA), the Potash and Phosphate Institute (PPI-PPIC) and the International Potash Institute (IPI). Later on, four workgroups dealing with nutrients, water, weeds and post harvest formed the International Rice Research Consortium (IRRC). This long term global commitment is an excellent example of a fruitful, long term partnership in research and extension, between donors, research and industry. IPI is striving for similar cooperation in the future with more crops in other regions.

Special thanks are due to Dr. Roland Buresh, senior soil scientist at IRRI and Dr. Christian Witt, Director of the South East Asia Program (SEAP), PPI-PPIC and IPI for their contribution to the 'Research Findings' section in this edition of *e-ifc*.

The other sections of this *e-ifc* edition include new publications, events and more.



*Countries in Asia with IPI projects mapped.*

178 years ago, Carl Sprengel (1787-1859) conducted basic and high impact research on soil fertility and plant nutrition, which led to the formation of the theory of the 'Law of Minimum'. Today, this basic theory guides us to continue research for even more efficient and sustainable plant nutrition. As 2006 is closing, we look to the future and wish our readers a happy, prosperous, fruitful year in 2007.

Hillel Magen
Director

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**Contents:**

# Research findings

## *I* Rice in Asia and the global food supply

Rice is the main staple food in Asia, where about 90% of the world's rice is produced and consumed.

China continues to be the world's biggest producer, growing one-third of Asia's total on 29 million ha (Table 1). India produces nearly a quarter on 43 million ha. Other top rice-producing countries in Asia include Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, the Philippines, and Japan. Average yields in these countries range from 2.6 t $ha^{-1}$ to 6.5 t $ha^{-1}$.

America, Africa, and Europe, however, continue to be net importers of rice.

The demand for rice is expected to grow for many years to come largely because of population growth, particularly in Asia, where population is expected to increase 35% by 2025 (United Nations 1999). An increase in total rice production may come from an increase in the area planted, increased yields, and increased cropping intensity. However, the scope for expansion of rice-growing areas is limited because of loss of agricultural land to urbanization, land conversion, and industrialization. Therefore, future increase in rice supply must come from increased yields and intensified cropping, particularly in the irrigated rice ecosystem.

There is substantial scope to increase current rice yields as farmers in Asia, on average, achieve only about 60% of the yield potentially achievable with existing varieties and climatic conditions. The main limitation to achieving higher yields and associated higher profitability for rice farmers per unit of arable land is often the ineffective use of inputs (particularly nutrients, seed, and pesticide) in an environmentally sustainable fashion. If the demand for food is to be met, rice production will need to become more efficient in the use of increasingly scarce natural resources. Better crop, nutrient, pest, and water management practices, along with the use of germplasm with a higher yield potential, are required in order for rice production to be profitable for producers and to supply sufficient affordable staple food for consumers.

| Country or Area | Production (Mio t) | Area harvested (Mio ha) | Yield (t $ha^{-1}$) |
|---|---|---|---|
| China | 179.0 | 28.7 | 6.2 |
| India | 129.2 | 42.8 | 3.0 |
| Indonesia | 52.4 | 11.7 | 4.5 |
| Bangladesh | 38.5 | 10.9 | 3.5 |
| Vietnam | 34.2 | 7.5 | 4.6 |
| Thailand | 26.1 | 9.9 | 2.6 |
| Myanmar | 22.7 | 6.2 | 3.6 |
| Philippines | 13.6 | 4.1 | 3.3 |
| Japan | 11.0 | 1.7 | 6.5 |
| Other Asian countries | 35.8 | 10.9 | 3.3 |
| Asia | 542.5 | 134.4 | 4.0 |
| World | 597.8 | 151.0 | 4.0 |

Table 1. Average annual rice production, area harvested, and yield in selected Asian countries, 2000-2005 (FAO 2006).

*Rice terraces in Bali, Indonesia.*

Worldwide, around 79 million ha of rice is grown under irrigated conditions. While this is only half of the total rice area, it accounts for about 75% of the world's annual rice production. In Asia, nearly 60% of the 130 million hectares devoted to rice production annually is irrigated, where rice is often grown in monoculture with two to three crops a year depending upon water availability (Huke and Huke, 1997). Other rice ecosystems include the rainfed lowland (35% of total rice area), characterized by a lack of water control, with floods and drought being potential problems, and the upland and deepwater ecosystems (5% of total rice area), where yields are low and extremely variable.

Thailand has maintained its position as the world's major rice trader, exporting an average of 8 million tons of rice annually (Fig. 1). Vietnam and India export a total of 7 million tons. A positive trade balance for rice has been maintained by Asia, Australia and the United States. Latin

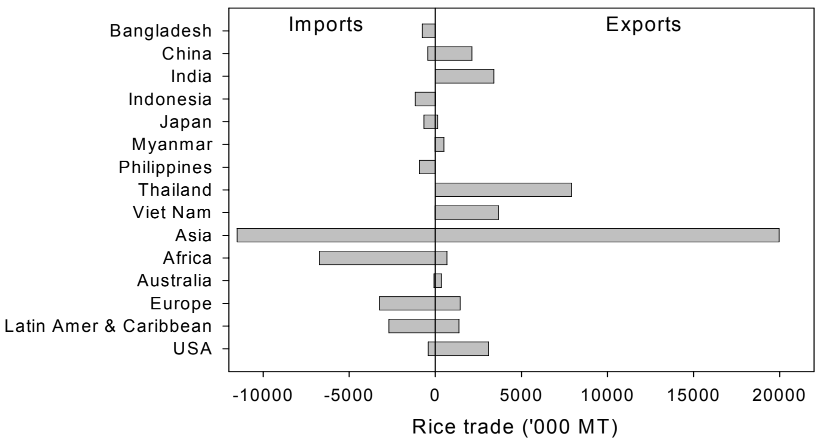


Fig. 1. Global rice trade. Data are the average of five years in 2000 to 2004 (FAO 2006).

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# Research findings

## *II* Ecological Intensification in Rice: Concept and Evaluation

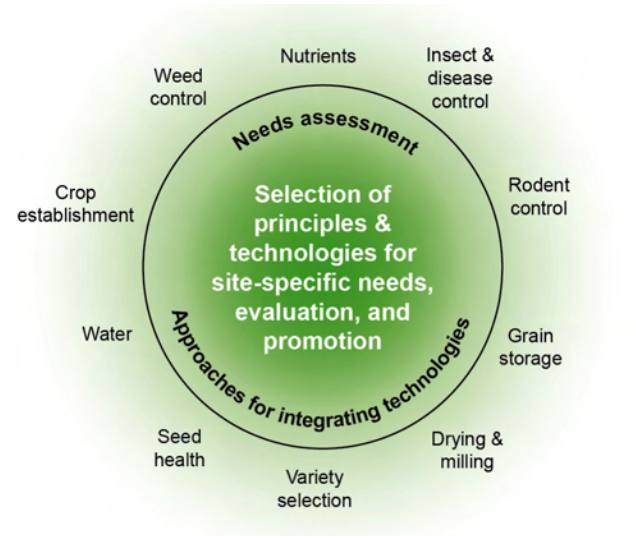
### Ecological intensification

The production of rice-based systems is expected to further intensify to meet the increasing global demand for rice, maize, vegetables, fruits, and other agricultural produce. The necessary ecological intensification aims to satisfy the anticipated increase in food demand while meeting acceptable standards of environmental quality (Cassman, 1999). An ecological intensification requires the identification of limiting constraints, a basket of management options from various disciplines, and an integration and participatory on-farm evaluation of the most promising practices at the site of concern. There is a need for relevant and robust performance indicators in the evaluation of interventions including standardized protocols for their measurement to arrive at evidence-based recommendations.

### Integration of technologies

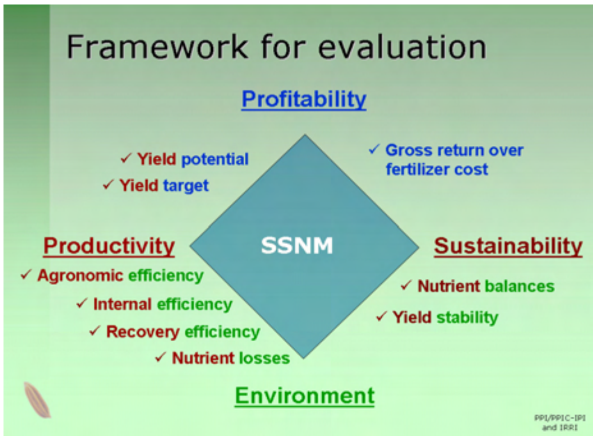
The simultaneous improvement in productivity, profitability, and input use efficiency - to name one indicator of environmental performance - will require sound decision support. There is a temptation to promote blanket discipline-based recommendations or integrated packages for vast areas but more knowledge-intensive and site-specific solutions will be required as yield gaps between actual and potential yield diminish. Matching the most limiting constraints to system productivity with adequate changes in management practices at the right scale remains a challenge. Great care is required in the development and promotion of integrated packages. Most problematic is the integration of technologies such as the 'System of Rice Intensification' or SRI (Dobermann, 2004; Sheehy *et al.,* 2004). SRI is not a science-based, integrated concept; it is a management package that was developed in adaptation to local needs and specific soil problems in Madagascar. The extrapolation of such locally adapted approaches to other locations without rigorous scientific evaluation bears the risk of ignoring local needs and is exposed to erratic validation.

The selection and integration of individual practices as and where required allows fine tuning of management systems at the local level in contrast to a promotion of one integrated water-weeds-pest-nutrient-crop management practice at the national level. In the latter case, a selection is made for the stakeholder regardless of whether one discipline needs to be considered at a location or not. It is a matter of transparency in the training of trainers versus delivering a blend of practices in a black box. However, we do need a better understanding and documentation of best management practices including expected interactions and synergies. The Irrigated Rice Research Consortium (IRRC, [www.irri.org/irrc](http://www.irri.org/irrc)) promotes the identification, integration, and evaluation of discipline-based management options at the field level, before the most promising combination of management practices is promoted in suitable domains with similar socio-economic and bio-physical conditions.




*A basket of technological options and their integration.*

Once a robust set of technologies is identified for a particular site, a local brand name could be developed to jointly promote the set of selected management practices with all stakeholders involved. It is important that each component of a local initiative that integrates more than one technology can be traced back to its original roots. Thus, one needs to go back to the original basket of management options when developing an integrated solution for a new location.




*Framework for the evaluation of Site-Specific Nutrient Management (SSNM) in irrigated rice.*

### Framework for the evaluation of Site-Specific Nutrient Management

The concept of ecological intensification is accompanied by a framework for the evaluation of interventions with clear guidelines on what parameters to measure and how to interpret them. The Southeast Asia Program (SEAP) of IPI and PPI/PPIC has developed such a framework for the evaluation of Site-Specific Nutrient Management (SSNM) in collaboration with the IRRC. Nutrient management strategies are evaluated considering productivity, profitability, sustainability, and environmental risks. The following performance indicators are used in the evaluation of SSNM:

**Agronomic efficiency (AE)** is the increase in grain yield per unit fertilizer nutrient applied. The AE is mainly used for N and ranges from 18 to 25 kg grain per kg fertilizer N applied with optimal management. At AE < 18 kg/kg, N could be managed inefficiently because of overuse, mismatch of plant N demand and supply, or other constraints to yield. At AE > 25 kg/kg, N supply could probably be too low to reach optimal yields.

# Research findings

**Internal efficiency (IE)** is the grain yield produced per unit plant nutrient. IE is an indicator of the efficiency with which the plant translates plant nutrients into grain yield. At optimal nutritional balance, about 68 kg grain is produced per kg plant N, 385 kg grain per kg plant P, and 69 kg grain per kg plant K (Witt *et al*., 1999). This translates into plant (not fertilizer!) nutrient requirements of about 15 kg N, 2.6 kg P, and 15 kg K per 1000 kg grain.

**Recovery efficiency (RE)** is the increase in plant nutrient per unit fertilizer nutrient applied. About 45-55% of applied fertilizer N is recovered by the plant under optimal management and growing conditions. If other factors are not limiting, RE largely depends on the amount of N applied, the timing of N application, the expected yield response to N application, and climatic factors such as temperature and wind speed.

**Nutrient losses** are calculated from the plant RE and changes in soil nutrient pools. Nutrient losses through percolation and run-off are usually small because irrigated rice is grown on heavy soils with levees. Nitrogen losses through volatilization can be minimized through best management practices and SSNM. The leaf color chart (IRRI 2006) is a management tool that farmers use to increase the RE of fertilizer N and reduce N losses to the environment.

**Yield potential (Ymax)** is the maximum theoretical yield determined by climate and variety. Ymax is used as guidance in the selection of a yield goal and to estimate the exploitable yield gap between Ymax and actual yield in farmers' fields.


*Home page of IRRC website: http://www.irri.org/irrc.*

Several crop models are available to estimate Ymax. The average yield potential in Asia is about 8.5 t ha$^{-1}$ but varies depending on site and season. The physiological yield barrier for rice in the tropics appears to be near 12 t ha$^{-1}$ and higher yields can only be reached in more temperate climates with cooler night temperatures and high solar radiation.

**Yield target** is the yield attainable by farmers with good crop and nutrient management and average climatic conditions. The selected yield goal should not be more than 75-80% of Ymax to avoid excessive fertilizer inputs and increased risk of crop failure and profit losses.

**Gross return over fertilizer cost (GRF)** is the revenue (rice yield x rice price) minus the total fertilizer cost. GRF is used to compare fertilizer programs and any new practice attractive to farmers is likely to require an increase in GRF. Recent surveys have shown that only 7% of farmers mentioned that the availability of cash or credit influenced their fertilizer management decisions in the irrigated lowlands. Fertilizer cost is only about 10-20% of GRF. The profitability of rice farming is therefore largely linked to the yield achieved by farmers.

**Nutrient balances and yield stability.** Preventive, long-term fertilizer P and K strategies are required to avoid nutrient depletion and ensure high N use efficiencies and yields. Negative P and K balances have to be expected when nutrient inputs from other sources such as straw or farmyard manure are lacking, and fertilizer is not applied because expected yield gains are small. This would lead to yield reduction in the long-term because of mining of soil nutrient supplies, particularly at elevated yield levels where nutrient removal with grain and straw is high. If only a small or no yield response is expected, fertilizer P and K rates need to be calculated based on a nutrient balance approach to meet the long-term P and K need and avoid soil nutrient depletion. Yield trends and changes in soil organic matter and nutrient stocks provide essential information in the assessment of management practices particularly when other crops are included in rice-based systems.

*Seedling preparation prior to transplanting of rice in West Java, Indonesia. (FAO 2006). Photo by S. Abdulrachman.*

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# Research findings

## *III* The principles of Site-Specific Nutrient Management

Rice requires an adequate supply of nutrients to achieve the high yields necessary to feed growing populations. Many of these nutrients come from soil and organic inputs, such as crop residues and manures; but high yields still require supplemental nutrients from fertilizer. Existing fertilizer recommendations for rice often advise fixed rates and timings of N, P, and K for vast areas of rice production. Such recommendations assume the need of a rice crop for nutrients is constant among years and over large areas. But crop-growth and crop-need for supplemental nutrients can be strongly influenced by crop-growing conditions, crop and soil management, and climate — which can vary greatly among fields, villages, seasons, and years.

**Site-specific nutrient management** (SSNM) as developed in Asian rice-producing countries provides an approach for 'feeding' rice with nutrients as and when needed (IRRI, 2006). SSNM strives to enable farmers to dynamically adjust fertilizer use to optimally fill the deficit between the nutrient needs of a high-yielding crop and the nutrient supply from naturally occurring indigenous sources, including soil, crop residues, manures, and irrigation water. The SSNM approach does not specifically aim to either reduce or increase fertilizer use. Instead, it aims to apply nutrients at optimal rates and times in order to achieve high rice yield and high efficiency of nutrient use by the rice, leading to high cash value of the harvest per unit of fertilizer invested.

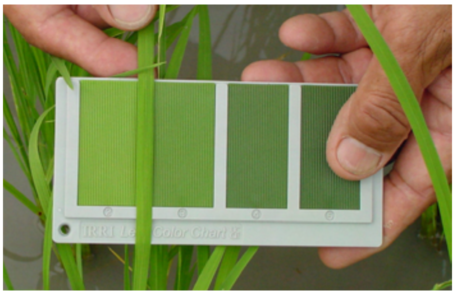
**The demand of rice for N** is strongly related to growth stage. In order to achieve high yield, rice plants require sufficient N at early and mid-tillering stages (branching) to achieve an adequate number of panicles (grain bunches), at panicle initiation stage to increase spikelet (flower) number per panicle, and during the ripening phase to enhance grain filling. The supply of N from soil and organic sources is seldom adequate for high yield, and supplemental N is typically essential for higher profit from rice fields. The SSNM approach enables farmers to apply fertilizer N in several doses to ensure the supply of sufficient N is synchronized with the crop need for N.

**A key ingredient for managing N** to meet crop need is a method for rapidly assessing leaf N content, which is closely related to photosynthetic rate and biomass production and is a sensitive indicator of the N demand during the growing season. A chlorophyll meter can provide a quick estimate of the leaf N status, but it is relatively expensive (Peng *et al*., 1996). The leaf color charts (LCC), on the other hand, is an inexpensive and simple tool for monitoring the relative greenness of a rice leaf as an indicator of the leaf N status (Balasubramanian *et al*., 1999; Witt *et al*., 2005). The LCC is typically a plastic, ruler-shaped strip containing four or more panels that range in color from yellowish green to dark green.

**SSNM provides two complementary** and equally effective options for improved N management using the LCC. In the 'real-time' N management option, farmers monitor the rice leaf color regularly (e.g. once a week) and apply fertilizer N whenever the leaves become more yellowish-green than the critical threshold value indicated on the LCC. In the 'fixed-time/adjustable dose' option, the time for N fertilization is pre-set at critical growth stages, and farmers adjust the dose of N upward or downward based on the leaf color.

**The real-time and fixed-time/ adjustable-dose** options for N management are typically comparable in terms of grain yield and profit when implemented according to the guidelines of SSSM. The selection of an option for using the LCC can be based on farmer preferences and location-specific factors. The fixed-time/adjustable-dose option, for example, is less time-consuming and is preferred by farmers with gainful non-rice activities and insufficient time for weekly visits to their rice fields. The real-time option is generally preferred when farmers lack sufficient understanding of the critical stages for optimal timing of fertilizer N. The effective management of N with both approaches, however, requires sufficient application of P, K, and micronutrients to overcome limitations of other nutrients.

**The SSNM approach advocates sufficient** use of fertilizer P and K to overcome P and K deficiencies, to avoid the mining of soil P and K and to allow




*The leaf color chart (LCC) for efficient N management in rice. © IRRI 2005.*

best N management. Fertilizer P and K requirements, sufficient to overcome deficiencies and maintain soil fertility, are determined with a nutrient decision support system (Witt and Dobermann, 2004), which maintains the scientific principles of the underlying QUEFTS model for rice (Janssen *et al*., 1990, Witt *et al*., 1999). Outputs of the nutrient decision support system have been summarized in Tables 1 and 2 (Witt *et al*., 2002), whereby fertilizer $P_2O_5$ and $K_2O$ rates are obtained from an estimate of attainable yield target and either the P- or K-limited yield. The yield target must be realistically attainable by farmers. It can be estimated from the grain yield in a fully fertilized plot with no nutrient limitations and good management (for example, the NPK plot or NPK plus micronutrient plot). P- and K-limited yields are determined by the nutrient omission plot technique.

**With the nutrient omission plot technique**, one plot of rice is grown with abundant fertilizer supplements (NPK plot or NPK plus micronutrient plot) and the yield thus achieved is used to calculate the

| Yield target (t/ha) → | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|
| P-limited yield (t/ha) ↓ | Fertilizer $P_2O_5$ rate (kg/ha) | | | | |
| 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 |

Table 1: Guidelines for the application of fertilizer $P_2O_5$ according to yield target and P-limited yield in P omission plots (Witt *et al*., 2002).

# Research findings

full demand of rice for P and K. The attained yield can also serve as a yield target. Rice is simultaneously grown in two other plots, one without added P fertilizer and the other without added K. The rice yield in the plot without fertilizer P provides an estimate of P-limited yield, and the rice yield in the plot without fertilizer K provides an estimate of K-limited yield. The yields are then used with Tables 1 and 2 to estimate optimal rate fertilizer $P_2O_5$ and $K_2O$ rates, which overcome P and K deficiencies and include sufficient P and K to prevent depletion of soil fertility arising from their long-term removal with grain and straw.

**Researchers developed the SSNM approach** in the mid 1990s and evaluated it from 1997 to 2000 on about 200 irrigated rice farms at eight sites in Asia. Since 2001, the on-farm evaluation and promotion of SSNM have markedly increased. In 2003 to 2005, SSNM was evaluated and promoted with farmers at about 20 locations in tropical and subtropical Asia (IRRI 2006), each representing an area of intensive rice farming.

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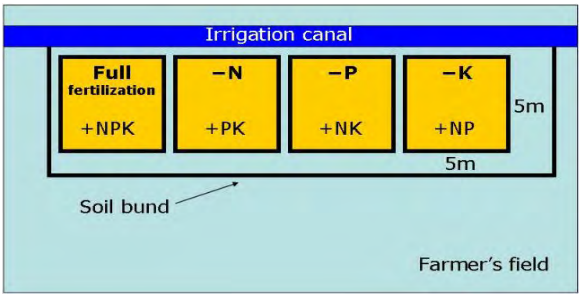


*Schematic layout of omission plot at farmers' field.*

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...potassium improved transfer of nitrogen and phosphorus from stems and leaves to panicles in rice plants… It could be concluded that K fertilizer application at the rate of 100 kg/ha per season was not high enough to match K output, and efficient K management for rice must be based on the K input/output balance.

*Source: HU Hong and WANG Guang-Huo 2004; Pedosphere 14(1):125-130.*

| Rice straw inputs | Yield target (t/ha) → | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|
| | K-limited yield (t/ha) ↓ | Fertilizer $K_2O$ rate (kg/ha) | | | | |
| Low (< 1 t/ha) | 3 | 45 | 75 | 105 | | |
| | 4 | 30 | 60 | 90 | 120 | |
| | 5 | 0 | 45 | 75 | 105 | 135 |
| | 6 | 0 | 0 | 60 | 90 | 120 |
| | 7 | 0 | 0 | 0 | 75 | 105 |
| | 8 | 0 | 0 | 0 | 0 | 90 |
| Medium (2–3 t/ha) | 3 | 30 | 60 | 90 | | |
| | 4 | 0 | 35 | 65 | 95 | |
| | 5 | 0 | 20 | 50 | 80 | 110 |
| | 6 | 0 | 0 | 35 | 65 | 95 |
| | 7 | 0 | 0 | 0 | 50 | 80 |
| | 8 | 0 | 0 | 0 | 0 | 65 |
| High (4–5 t/ha) | 3 | 30 | 60 | 90 | | |
| | 4 | 0 | 30 | 60 | 90 | |
| | 5 | 0 | 0 | 30 | 60 | 90 |
| | 6 | 0 | 0 | 10 | 35 | 70 |
| | 7 | 0 | 0 | 0 | 25 | 55 |
| | 8 | 0 | 0 | 0 | 0 | 40 |

Table 2. Guidelines for the application of fertilizer $K_2O$ according to yield target and K-limited yield in K omission plots (Witt *et al*., 2002).

# Research findings

### *IV* Reaching Towards Optimal Productivity

The workgroup “Reaching Toward Optimal Productivity” (RTOP) of the Irrigated Rice Research Consortium (IRRC) has been instrumental in the development, evaluation, and promotion of Site-Specific Nutrient Management (SSNM) as an approach for increasing farmers’ profit through more efficient use of nutrients (IRRI 2006).

In January 2001, the RTOP workgroup was established with funding from the Swiss Agency for Development and Cooperation (SDC), the International Fertilizer Industry Association (IFA), The International Potash Institute (IPI), and the Potash & Phosphate Institute (PPI-PPIC). The workgroup supported nutrient management-related research and the delivery of SSNM through partnerships with the National Agricultural Research and Extension Systems (NARES) in Bangladesh, China, India, Indonesia, Myanmar, the Philippines, Thailand, and Vietnam.

As a result of RTOP, the principles and practice of SSNM for rice have been well formulated and widely recognized across Asia. These SSNM principles have subsequently been utilized by partners across Asia to develop location-specific nutrient management practices for major rice-growing area.

Since 2001, the RTOP Workgroup of the IRRC has collaborated with NARES in eight Asian countries to systematically transform the initial SSNM concept (developed since 1994) into an inclusive, simplified framework for the dynamic plant-need based management of N, P, and K (IRRI 2006). The SSNM approach now enables: 1) dynamic adjustments in fertilizer N, P, and K management to accommodate field- and season-specific conditions; 2) effective use of indigenous nutrients; 3) efficient fertilizer N management through the use of the leaf color chart (LCC), which helps ensure N is applied at the time and in the amount needed by the rice crop; 4) use of the omission plot technique to determine the requirements for P and K fertilizer; and 5) use of micronutrients based on local recommendations.

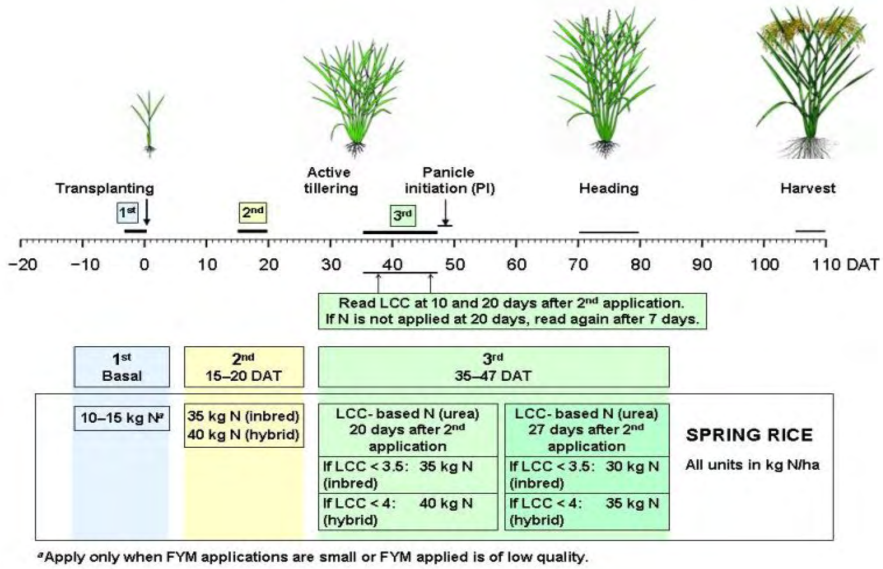


Fig. 1. Recommended N management for transplanted rice with growth duration of 120−125 days in the spring season in the Red River Delta (northern Vietnam).

#### *Improved nitrogen management*

The general principles for N fertilizer management with SSNM include: a) the application of only a moderate amount of N to young rice, within the first 14 days after transplanting (DAT) for transplanted rice or first 21 days after sowing (DAS) for direct-seeded rice, when the demand for N is small; and 2) the dynamic management of fertilizer N to ensure sufficient supply of N to the crop at the critical growth stages of mid-tillering and panicle initiation.

Table 1 presents for four locations an example of developing an N recommendation based on data collected during 2001-2004 high-yielding season. Yields obtained with sufficient N, P, K, (and Zn where needed) to eliminate deficiencies of these nutrients were considered as yield targets. The attainable yield with NPK was comparable among three sites (Cauvery Delta in India, Nueva Ecija in the Philippines, and Mekong Delta in Vietnam), which ranged from 5.6 to 7.4 t/ha. The Red River Delta (RRD) in Vietnam showed the highest attainable yield with NPK (6.8 – 8 t/ha). Yield without N fertilizer was also highest in the RRD, indicating the effect of heavy application of farm yard manure (about 10 t/ha/crop) by farmers. The N-limited yield gap, which is the response to N application, was similar across the four locations and ranged from 1.4 to 3.2 t/ha. Hence, the approximated fertilizer N requirement was also comparable among

| Parameter | India (Cauvery Delta) (*n* = 61) | Philippines (Nueva Ecija) ( *n* = 21) | Vietnam (Mekong Delta) (*n* = 56) | Vietnam (Red River Delta) (*n* = 60) |
|---|---|---|---|---|
| Attainable yield with NPK (t/ha) | 5.6 – 7.2 | 5.6 – 7.0 | 5.6 – 7.4 | 6.8 – 8.0 |
| Yield without N fertilizer (t/ha) | 3.2 – 4.8 | 3.4 – 4.8 | 3.5 – 4.9 | 4.3 – 5.9 |
| Crop response to N fertilizer (t grain/ha) | 1.6 – 3.2 | 1.4 – 3.2 | 1.6 – 3.0 | 1.6 – 3.0 |
| Targeted agronomic efficiency of applied N (Δkg grain/kg N) | 23 | 23 | 23 | 23 |
| Approximate fertilizer N requirement (kg N/ha) | 70 – 136 | 60 – 136 | 71 – 127 | 71 – 133 |
| Estimated number of N applications during the season | 3 – 4 | 3 – 4 | 3 – 4 | 3 – 4 |
| N dose for each application of fertilizer N (kg N/ha) | 20 – 45 | 20 – 45 | 20 – 35 | 10 – 40 |

Table 1. Attainable yield with NPK fertilization, crop response to N fertilizer, and N fertilizer requirements for the high-yielding season at four locations in 2001-04.

# Research findings

the four locations when a uniform agronomic efficiency of N (AEN, 23 kg increase in grain per kg of N applied) is targeted.

Fig. 1 and 2 show examples of N recommendations that indicate amount and timing of N applications as developed through the SSNM approach (IRRI, 2006). Early N applications are small and vary depending on the amount and quality of applied farmyard manure (FYM) or organic materials, as shown by the low rate of basal N (10-15 kg N/ha) in northern Vietnam where FYM application is common and the higher rate of early N (30 kg N/ha) in the Philippines where application of organic source of N is minimal. Rates of N application during the critical growth stages of tillering and panicle initiation are adjusted based on plant need for nitrogen as indicated by leaf color.

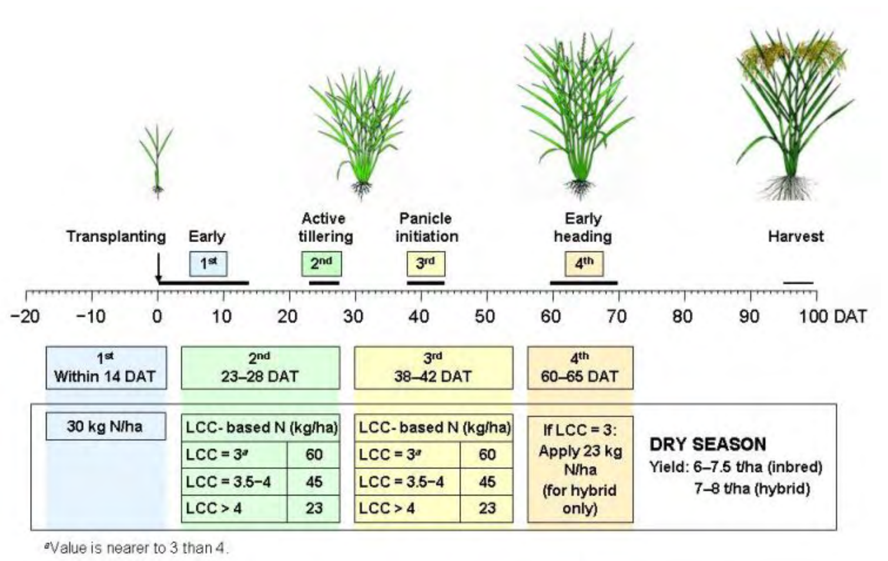


Fig. 2. Recommended N management for transplanted rice with growth duration of 115−120 days in Nueva Ecija, Philippines.

***Improved P and K management***

Through the process of developing and evaluating SSNM, the nutrient omission plot technique was conducted on numerous farmers' fields in the different RTOP sites from 2001-2004. Yields for fully fertilized plots (no N, P, K, and Zn constraints to crop growth), yields for P-omission plots, and yields for K-omission plots varied among years and farmers' fields depending upon climate and crop management practices.

Crop responses to P and K (i.e., the differences between yields in NPK plots and yields in nutrient omission plots) varied within a range of 1 t/ha for each of the five locations as shown in Table 2. More than 1 t/ha response to P was obtained in the Mekong Delta (MD) and the RRD Vietnam, and in some cases also in Nueva Ecija, Philippines. Crop response to K was generally higher (> 0.5 t/ha) in the RRD and the New Delta (Southern India) than the other three locations (Table 2).

Fertilizer P and K requirements — estimated using NuDSS software (Nutrient Decision Support System for rice, Witt *et al*., 2005), which maintains the scientific principles of the underlying QUEFTS model for rice (Witt *et al*., 1999, Janssen *et al*., 1990) — varied depending on yield target (yield with NPK), crop response to P or K, and the amount of organic inputs (e.g. rice straw, FYM). Fertilizer P requirements for the high-yielding season in Southern India (Old and New Delta) and the Philippines were comparable and ranged from 25 to 36 kg $P_2O_5$/ha (Table 2). MD had the highest P requirement (26-40 kg $P_2O_5$/ha) because of the very low organic input (0.5 t straw/ha/crop) and the relatively low P supply as indicated by a high crop response to P (0.7-1.7 t/ha), while RRD had the lowest fertilizer P requirement (9-25 kg $P_2O_5$/ha) due to the heavy application of FYM (about 10 t/ha/crop) (Table 2). Since large applications of FYM are common in the RRD, the estimated fertilizer K requirements for that location were low (17-47 kg $K_2O$) despite the high crop response to K (0.6-1.6 t/ha). Estimated fertilizer K requirements were highest in Southern India due to low straw input, especially in the New Delta (57-87 kg $K_2O$/ha) where a higher crop response to K (0.5-1.1 t/ha) was indicated (Table 2).

| Parameter | India (Cauvery Delta) | | Philippines | Vietnam | |
|---|---|---|---|---|---|
| | Old Delta ($n$ = 29) | New Delta ($n$ = 32) | Nueva Ecija ($n$ = 21) | Mekong Delta ($n$ = 56) | Red River Delta ($n$ = 60) |
| Attainable grain yield with NPK (t/ha) † | 5.4 – 7.0 | 5.7 – 7.3 | 5.6 – 7.0 | 5.6 – 7.4 | 6.8 – 8.0 |
| Crop response to P fertilizer (t grain/ha) † | 0 – 0.6 | 0.2 – 0.8 | 0.1 – 1.1 | 0.7 – 1.7 | 0.4 – 1.2 |
| Crop response to K fertilizer (t grain/ha) † | 0.2 – 0.8 | 0.5 – 1.1 | 0 – 0.9 | - | 0.6 – 1.6 |
| Estimated amount of straw returned (t/ha) | 1.0 | 1.0 | 2.5 | 0.5 | - |
| Farmyard manure application (t/ha) | - | - | - | - | 10 |
| Estimated P requirement (kg $P_2O_5$/ha) † | 25 – 33 | 26 – 36 | 25 – 33 | 26 – 40 | 9 – 25 |
| Estimated K requirement (kg $K_2O$/ha) † | 50 – 78 | 57 – 87 | 29 – 57 | - | 17 – 47 |

Table 2. Attainable yield, P and K deficits, and estimated P and K requirements during the high-yielding season at five locations in three countries in 2001-04.

# Research findings

**Benefits of SSNM**

***Yield increase and economic benefits with SSNM***

Grain yield obtained in on-farm evaluation of SSNM from 2001-2004 showed an increased yield with SSNM as compared to farmers' fertilizer practice (FFP), consistently across four locations and for both high- and low-yielding seasons (Fig. 3). A comparison of the economic benefits in terms of gross return above fertilizer cost (GRF) derived using SSNM and FFP for two years (2003-2004) in the Red River Delta (Northern Vietnam) revealed a higher GRF for SSNM than for FFP (Table 3). The added benefit from using SSNM amounted to US\$ 147 for two crops per year (Table 3).

***Fertilizer N use efficiency and its impact in the environment***

The use of SSNM resulted to increased yields and higher N use efficiency (i.e., partial factor productivity, $PFP_N$, expressed as kg grain per kg applied N) as compared to farmers' fertilizer practice (FFP) without necessarily reducing application rates of fertilizer N (Table 4).

Simulations with DNDC model (DeNitrification-DeComposition); (Li, 2000; Li *et al.*, 2004) showed possible benefits of SSNM on reduced global warming potential (GWP) associated with reduced emissions of $N_2O$. The GWP expressed per unit of grain yield and unit of fertilizer N was significantly reduced by SSNM at all three sites in Southern Vietnam (Table 4, next page). Treatment differences in Southern India and the Philippines were not significant, although a reduction in GWP with SSNM was also indicated in the Philippines. The simulated reduction in GWP with use of SSNM averaged 49 kg carbon dioxide equivalent (CDE) $t^{-1}$ grain in the Philippines and 62 kg CDE $t^{-1}$ grain in Vietnam (Table 4). This corresponded to an average reduction of 56 kg CDE $t^{-1}$ grain across the two countries or a 22% reduction in CDE per unit of rice produced. There was no reduction in GWP due to SSNM in Southern India probably because the efficiency of fertilizer N (e.g. $PFP_N$) and yields were already relatively high with FFP (Table 4). The simulated $N_2O$ emissions were low (data not shown), perhaps as a reflection of the already relatively high efficiency of fertilizer N use. In such cases, SSNM was able to increase yield with the same (Old Delta) or increased (New Delta) rate of fertilizer N without additional $N_2O$ emission per unit of grain yield or fertilizer used.

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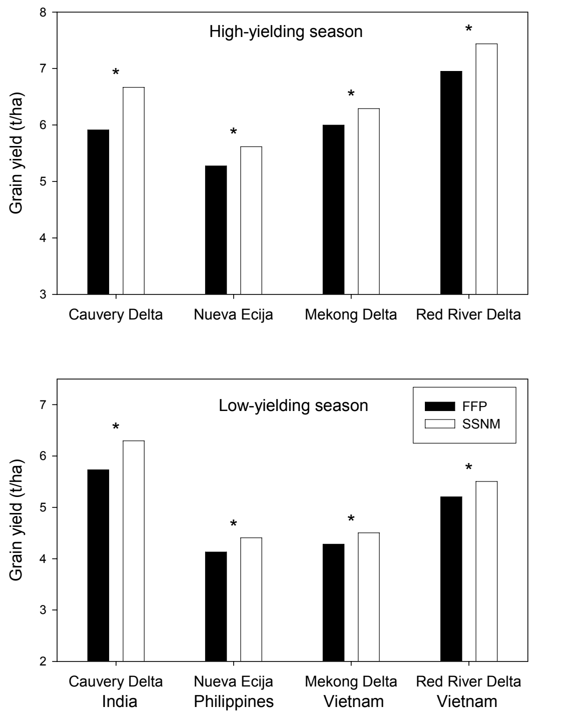


Fig. 3. Grain yield obtained with farmers' fertilizer practice (FFP) and site-specific nutrient management (SSNM) conducted in farmers' fields at four locations in 2001-04. The asterisk (*) indicates a significant difference between the two treatments at $P<0.05$. The total number of farmers per location participating in these evaluation trials ranged from 44 to 90 in the high-yielding season and 47−112 in the low-yielding season.

| Parameter | Unit | Spring rice | | Summer rice | | Annual total | |
|---|---|---|---|---|---|---|---|
| | | FFP | SSNM | FFP | SSNM | FFP | SSNM |
| Grain yield | t/ha | 6.95 | 7.44 | 5.21 | 5.51 | 12.16 | 12.94 |
| Gross returns (GR)† | US\$/ha | 960 | 1027 | 784 | 829 | 1744 | 1856 |
| Fertilizer N application | kg N/ha | 114 | 87 | 117 | 85 | 231 | 172 |
| Fertilizer P application | kg P/ha | 31 | 26 | 34 | 25 | 65 | 51 |
| Fertilizer K application | kg K/ha | 63 | 76 | 63 | 76 | 126 | 152 |
| Total cost of fertilizers (FC) | US\$/ha | 117 | 103 | 130 | 107 | 246 | 210 |
| Gross return above fertilizer cost (GRF) ‡ | US\$/ha | 844 | 924 | 655 | 722 | 1498 | 1645 |
| Added benefit from SSNM § | US\$/ha | | 80 | | 67 | | 147 |

† Gross returns (GR) = grain yield x price of grain;

‡ Gross returns above fertilizer cost (GRF) = GR – FC;

§ Added benefit from SSNM = $GRF_{SSNM} - GRF_{FFP}$

Table 3. Economic benefit derived with using improved N, P, and K management with site-specific nutrient management (SSNM), averaged over two years (2003-04) and 60 farms across five soil types in the Red River Delta, northern Vietnam. Actual costs of produce and inputs were used.

# Research findings

| Country | Location | Nutrient management practice[†] | Applied fertilizer (kg N $ha^{-1}$) | Annual yield (t $ha^{-1}$) | Partial factor productivity (kg grain $kg^{-1}$ applied N) | GWP[‡] expressed as carbon dioxide equivalent (CDE) (kg $t^{-1}$ grain yield) | (kg $kg^{-1}$ fertilizer N) |
|---|---|---|---|---|---|---|---|
| India | Old Delta (n = 5) | FFP | 258 | 12.4 | 48 | 61 | 2.8 |
| | | SSNM | 256 | 12.9 | 51 | 58 | 2.9 |
| | | *Prob > t* [§] | *0.75* | *0.004* | *0.23* | *0.66* | *0.85* |
| | New Delta (n = 5) | FFP | 201 | 11.6 | 58 | 81 | 4.7 |
| | | SSNM | 241 | 12.8 | 53 | 89 | 4.7 |
| | | *Prob > t* | *<0.001* | *<0.001* | *0.01* | *0.31* | *0.87* |
| Philippines [¶] | Nueva Ecija (n = 10) | FFP | 249 | 9.7 | 39 | 415 | 15.8 |
| | | SSNM | 225 | 10.4 | 47 | 366 | 16.7 |
| | | *Prob > t* | *0.07* | *0.004* | *0.02* | *0.22* | *0.38* |
| Vietnam [#] | An Giang (n = 5) | FFP | 197 | 9.3 | 47 | 212 | 9.6 |
| | | SSNM | 174 | 9.6 | 55 | 160 | 8.5 |
| | | *Prob > t* | *0.006* | *0.24* | *<0.001* | *<0.001* | *<0.001* |
| | Cantho (n = 5) | FFP | 224 | 9.4 | 42 | 180 | 7.5 |
| | | SSNM | 189 | 10.3 | 55 | 116 | 6.3 |
| | | *Prob > t* | *<0.001* | *0.002* | *<0.001* | *<0.001* | *<0.001* |
| | Tien Giang (n = 5) | FFP | 218 | 8.8 | 41 | 201 | 8.0 |
| | | SSNM | 188 | 9.6 | 51 | 130 | 6.6 |
| | | *Prob > t* | *0.001* | *0.003* | *<0.001* | *<0.001* | *0.003* |

Table 4. The contribution of simulated $N_2O$ emission from soil and fertilizer to annual global warming potential (GWP) as influenced by nutrient management practices based on measured on-farm annual rice yields and fertilizer N application rates in three countries for two irrigated rice crops in 2002-03.

[†] FFP is farmers' fertilizer practice and SSNM is site-specific nutrient management (Pampolino et al., 2006). [‡] GWP based on $N_2O$ emissions from soil and fertilizer as simulated by DNDC (Li 2000; Li *et al*., 2004); [§] Probability level of the difference between FFP and SSNM; [¶] Two crop establishment methods with five farms per method; there was no crop establishment x treatment interaction, hence values shown are means of the two crop establishment methods; [#] Sites included are only for Southern Vietnam (Mekong Delta).

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*Grain yield in N omission plots (-N, +P, +K) is used to estimate the indigenous supply of N from soil and other non-fertilizer sources.*

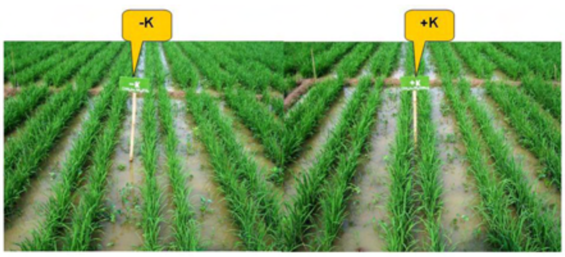

*Grain yield in K omission plots (-K, +N, +P) is used to estimate the indigenous supply of K from soil and other non-fertilizer sources.*


*Grain yield in P omission plots (-P, +N, +K) is used to estimate the indigenous supply of P from soil and other non-fertilizer sources.*

# Research findings

## *V* The need for Potassium fertilization in rice and experiences from a long-term experiment in Indonesia

Rice is the staple food of the Indonesian people, and it accounts for more than half of their caloric intake. Rice production is a source of livelihood for more than 200 million people in the country, especially in the lowlands. The total land area cultivated to rice is close to 12 million hectares, and in 1987 irrigated rice covered 58% of the total cultivated rice area. Java is the main producer of rice. With increasing population and decreasing area for rice cultivation in the fertile lowlands due to urbanization and industrialization, it is important that the long-term sustainability of the irrigated rice production system in Indonesia be assessed. The Long-Term Fertility Experiment (LTFE) at the Indonesian Center for Rice Research (ICRR), Sukamandi, West Java was initiated in 1995 to assess the long-term changes in soil nutrient supply, nutrient balance, nutrient use efficiency, yields, and overall sustainability of a double rice cropping system.




*Field experiment in Sukamandi Experiment Station, Indonesia. Photo by H. Magen.*

Results for 21 cropping seasons (or 10.5 years of intensive cropping) indicate that with balanced fertilization of N, P, and K grain yield averaged 5.5 t ha$^{-1}$ in the dry season and 6.5 t ha$^{-1}$ in the wet season. The accumulated loss in grain yield without application of fertilizer N was 40 t ha$^{-1}$ across the 21 cropping seasons (Fig. 1). This corresponded to an average grain yield loss of 2 t ha$^{-1}$ in each season if fertilizer N was not used. Thus, the use of fertilizer N with appropriate amounts of fertilizer P and K ensured an average additional grain yield of 2 t ha$^{-1}$ in each season.

Based on the site-specific nutrient management (SSNM) approach for fertilization of rice (IRRI 2006), a rice crop requires about 50 kg fertilizer N per hectare for each ton in additional grain yield. The optimal amount of fertilizer N required to attain the yield targets of 5.5 t ha$^{-1}$ in the dry season and 6.5 t ha$^{-1}$ in the wet season at this site was consequently near 100 kg N ha$^{-1}$. This amount of fertilizer N can be split into three doses with an early N application of about 20 to 30 % of the total requirement. The remaining 70 to 80% is split into two doses with the timing of N application based on the need of the rice crop, as determined from leaf color using the leaf color chart.

Farmers in West Java often believe the supply of K in the soil is sufficient for high rice yields and hence there is no need to apply fertilizer K to their rice fields. However, results of the LTFE show that the total loss in yield without application of fertilizer K was 10 t ha$^{-1}$ across the 21 seasons (Fig. 1). For the first eleven seasons, there was a slow decline in yield (0.3 t ha$^{-1}$ per crop) without K fertilization. But then from the 12th season onwards the yield loss increased to 0.6 t ha$^{-1}$ per crop. The results indicate that with continuous cropping, K becomes depleted in the soil, and thus it should be replenished for the attainment of high yields. With fertilizer K application, there was an average increase in grain yield of 0.5 t ha$^{-1}$ per season.

Based on the SSNM approach, the rice crop requires an estimated 40 kg $K_2O$ ha$^{-1}$ to achieve a yield target of 6.5 t ha$^{-1}$ in the wet season and 25 kg $K_2O$ ha$^{-1}$ to attain the yield targets of 5.5 t ha$^{-1}$ in the dry season (Fairhurst and Witt, 2002). This is based on an average yield response of 0.5 t ha$^{-1}$ in each wet- and dry-season.

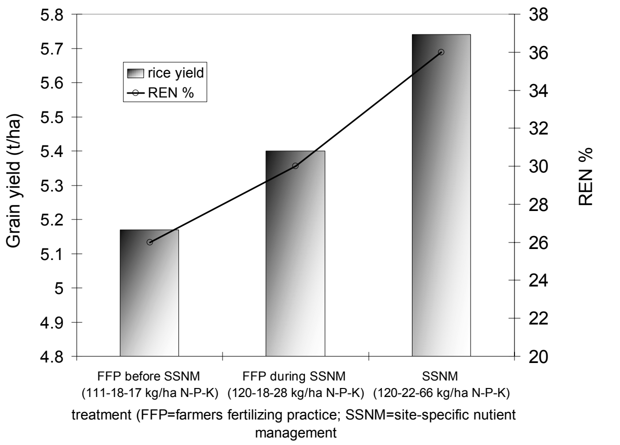



Fig. 2: Impact of balanced fertilization on grain yield of rice and recovery of fertilizer N. REN = Recovery Efficiency of N.

The application of sufficient fertilizer K to overcome deficiency of K can increase the efficiency of fertilizer N use. Fig. 2 illustrates a situation where the rate of fertilizer N application (120 kg N ha$^{-1}$ was sufficient with adequate application of fertilizer P and K to achieve a rice yield of 5.7 t ha$^{-1}$ (SSNM treatment). With insufficient fertilizer K the yield was 5.2–5.4 t ha$^{-1}$ (FFP before and during SSNM). The application of additional fertilizer K, through an increase in yield with no additional use of fertilizer N, increased the recovery efficiency of fertilizer N by the rice crop (REN) to 37% of the applied fertilizer N (Dobermann, 1999; Fig. 2).

The actual amount of fertilizer K required in a specific field depends upon the

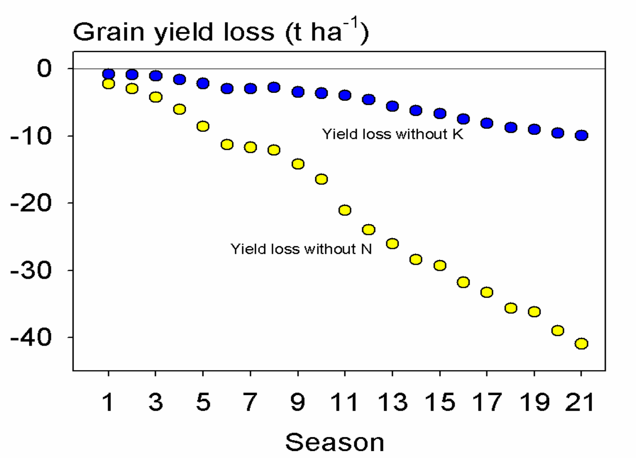



Fig. 1. Loss in rice grain yield after 21 crops (1995 to 2005) when nitrogen and potassium fertilizers are not applied. Long Term Fertility Experiment, Sukamandi Experiment Station, Indonesia.

# Research findings

quantity of crop residues returned to the soil, the quantity of K in irrigation water, and the soil properties. A simple tool to assess whether a rice field is deficient in K and to determine the quantity of required fertilizer K is the 'K addition plot' (as all the field is a large K omission plot). With this technique, a small plot (5m x 5m) is placed in a farmer's field and fertilizer K is applied to the rice plants in the plot. The increase in grain yield in the K addition plot compared to the rest of the field indicates the benefit and need for fertilizer K application. Addition plots are a useful tool to decide whether the current rate of fertilizer K used by farmers should be increased. It should be noted that the greatest benefit from K application is often only achieved with optimal management of other nutrients and best management practice.

*Acknowledgment: The long-term fertility experiment was conducted by Dr. Sarlan Abdulrachman and other scientists at the Indonesian Center for Rice Research.*

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*Home page of SSNM website: http://www.irri.org/irrc/ssnm/ home page.*

### *VI* Nutrient Decision Support Systems (NuDSS) for Irrigated Rice

The Nutrient Decision Support System (NuDSS) for irrigated rice is part of an initiative by the Irrigated Rice Research Consortium (IRRC) to provide decision support on Site-Specific Nutrient Management (SSNM) in the irrigated lowlands (Witt *et al.,* 2005). The content of the software is consistent with earlier publications on SSNM including a handbook and practical guide. The NuDSS software adds value to these materials by combining various models into one user-friendly software package to assist in the development of improved fertilizer strategies for effective fertilizer use, high and sustainable yields, and increased farmers' profit.

The software was developed recognizing the need for decision aids providing assistance in complex mathematical calculations (e.g., though optimization routines) that would be difficult to perform otherwise.

NuDSS is a generic decision support system for irrigated rice capturing the most important cropping conditions in tropical and sub-tropical Asia. The underlying principles of plant nutrition are valid for all modern, high-yielding rice varieties with a harvest index of about 0.50 kg $kg^{-1}$. Crop- and site-specific conditions are specified in a general settings menu, including guidelines for local adaptation when conditions divert from the standard situations.

### Decision framework

Based on the general framework for decision support depicted in Fig. 1, the development of improved fertilizer recommendations may include six major steps with the following outputs:

1. *Estimate recommendation domains and indigenous nutrient supplies.* Larger areas are divided into smaller agro-ecological recommendation domains. Domain sizes determine the required number of nutrient omission plots that are used to obtain average N, P and K limited yields (estimates of indigenous nutrient supplies) valid for the domain (Dobermann *et al.,* 2003a; Dobermann *et al.,* 2003b).

2. *Select a yield target.* Season-specific yield targets are set to be about 10% greater than currently achieved in farmers' fields but not more than 80-85% of the yield potential (Witt *et al.,* 2002).

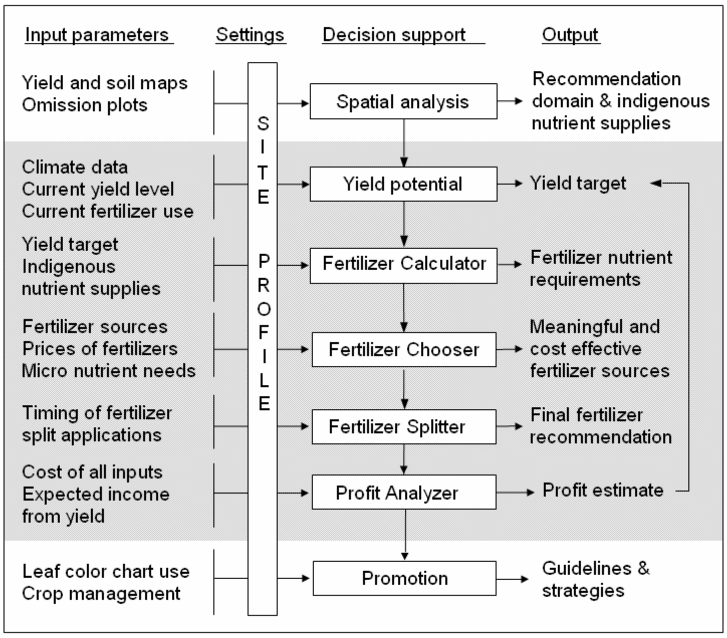


Fig. 1. Flow chart of the Nutrient Decision Support System (NuDSS) for irrigated rice. The grey area portrays the software modules available in the NuDSS software. Adapted from (Witt and Dobermann, 2004).

# Research findings

3. *Calculate fertilizer nutrient requirements*. Total fertilizer N, P and K requirements are calculated based on expected fertilizer nutrient requirements of 40-50 kg N, 20 kg $P_2O_5$, and 30 kg $K_2O$ per ton of required yield increase. Requirements for P and K are adjusted using an input-output balance to prevent soil nutrient depletion due to nutrient removal with grain and straw (Witt *et al.*, 2002; Witt and Dobermann, 2004).

4. *Select meaningful fertilizer material*. Fertilizer rates of elemental nutrients (kg $ha^{-1}$) are expressed in nutrient sources per local area unit to facilitate wider-scale promotion.

5. *Obtain profit estimate*. The existing practice is compared with the newly developed alternative nutrient management strategy to obtain an estimate of the expected profit increase (ex-ante analysis). Fertilizer strategies are adjusted depending on the outcome of the economic analysis (Witt and Dobermann, 2004).

6. *Simple guidelines and strategies for promotion*. Where farmers' fertilizer use is inadequate, it may be most effective and economic to develop, evaluate and locally adapt improved fertilizer recommendations through farmer participation and then promote new guidelines in suitably large areas, including guidelines for further adjustments (Buresh *et al.*, 2005). The NuDSS software aims to facilitate this process.


*Home screen of NuDSS.*

*Software, tutorial, and background information on the principles of SSNM can be downloaded at the websites of PPI/PPIC-IPI (www.seap.sg) and IRRI (www.irri.org/science/software).*

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*Ripple, a new quarterly newsletter produced by the Irrigated Rice Research Consortium (IRRC): http://www.irri.org/irrc/ripple.asp.*

*Paddy field after harvest. What is the fate of the potassium rich crop residues?*

*Photo in China, by H. Magen.*

**Acknowledgment**

The development of SSNM for rice was made possible through support from the Swiss Agency for Development and Cooperation (SDC), the International Fertilizer Association (IFA), the Potash and Phosphate Institute/Potash and Phosphate Institute of Canada (PPI/PPIC) and the International Potash Institute (IPI).

# Research findings

## *VII* Farmer participatory development and evaluation of locally adapted nutrient management practices

Below is a description of a farmer participatory approach for the development, evaluation, and promotion of nutrient management practices tailored to the field-specific needs of Asian rice farmers. This has emerged through collaboration between NARES and IRRI in several Asian countries, including Indonesia and the Philippines.

*Step 1: Train local extension workers, researchers, and farmer leaders on guidelines for enabling rice farmers to develop field-specific nutrient management practices*

The effective uptake by farmers of a relatively knowledge intensive technology, such as improved nutrient management for rice, necessitates the communication of consistent and explicit messages to farmers. The persons providing farmers with information on nutrient management must be familiar with the SSNM guidelines and how they can be used by farmers to develop and evaluate improved practices for specific rice fields. The implementation of this step requires:

- Technical experts to serve as trainers.
- A manual explaining how to enable rice farmers to develop and evaluate improved nutrient management practices for their specific rice fields.

*Step 2: Empower farmers to develop nutrient management practices adapted to their specific rice fields*

Trained extension workers, researchers, or farmer leaders can interact with farmers in a target community through a focus group discussion. This empowers farmers, through a series of questions based on the steps in the SSNM guidelines presented in section *IV*, to develop a nutrient management practice tailored to specific rice fields. The implementation of this step requires:

- Appropriate selection of farmers within a target community.
- Documentation, such as a flip chart, to guide farmers through the process of developing a nutrient management practice.

*Step 3: Work with farmers in a target community to formulate and demonstrate a mutually agreed upon nutrient management practice.*

A demonstration plot can provide farmers with visible evidence for the merits of an alternative nutrient management practice. The focus group discussion can be used to select the field for the demonstration and then develop, through a participatory process with farmers, a mutually agreeable nutrient management practice to be demonstrated in the field. The SSNM guidelines for example allow farmers to select whether to use single element or compound (NPK) fertilizer sources.

In implementing SSNM at the field and farm level, more uncertainty often exists regarding the optimal rate of fertilizer K and whether to apply a micronutrient such as zinc than with the optimal management for fertilizer N and P. The SSNM demonstration field can therefore include two improved practices for evaluation. For example, if through the focus group discussion there is considered to be a high likelihood of insufficient fertilizer K use with the farmers' practice, then one half of the SSNM demonstration field can receive only the recommended early fertilizer K application, which is typically higher than the farmers' practice. The other half of the SSNM demonstration field can receive both the recommended early fertilizer K application and the recommended fertilizer K application at panicle initiation. This can be valuable in demonstrating the merits of contrasting fertilizer K rates to farmers often unfamiliar or hesitant with the use of fertilizer K. On the other hand, if through the focus group discussion there is considered to be a high likelihood of zinc deficiency, then zinc sulfate can be applied to only one half of the SSNM demonstration plot field in order to assess the merit of zinc fertilization.

*Farmers' meeting in the Mekong Delta, Vietnam. Photo by R. Buresh.*

*Step 4: Use the focus group discussion to provide farmers with techniques to diagnosis and overcome nutrient constraints in their fields*

The need for fertilizer K and micronutrients, such as zinc, can vary among fields. For example, the need for fertilizer K is influenced by straw management and soil properties, whereas the need for zinc is influenced by duration of soil submergence. Through a focus group discussion, farmers' fields with high likelihood of K or zinc deficiency can be identified and targeted for evaluation of the needs of these nutrients.

The need for zinc fertilization can be determined by applying zinc sulfate at early rice growth stage to a small plot, typically about 5 m by 5 m, within a farmers' field. Comparative performance of the rice crop within the zinc addition plot and in an adjacent comparably managed area without application of zinc can be used to assess the need for zinc (IRRI, 2006). Similarly, the need for supplemental fertilizer K can be determined by applying KCl (0-0-60) fertilizer to a small plot within a farmers' field and assessing the comparative performance of the rice crop within the K addition plot and in an adjacent comparably managed area without application of additional K. The implementation of this step requires:

- Pre-weighed fertilizers packets with sufficient zinc sulfate or KCl for application to a pre-determined field area.
- Simple instructions for farmers on how to implement K and zinc addition plots to assess the need for these nutrients.

The fertilizer, instructions, and brief training are provided to farmers, and then farmers completely implement the simple trial in their field. The K and zinc addition plot trials can be supplemented with soil test kits and soil analyses to enhance abilities for predicting locations most prone to K and zinc constraints.

# Research findings

*Step 5: Conduct periodic farmer meetings and field visits*

Field visits provide farmers in a community with the opportunity to observe crop performance in demonstration plots and in zinc or K addition plot trials. Periodic field visits and farmer meetings can provide farmers with answers to questions arising from demonstrations and with orientation to SSNM guidelines.

**References**

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## *VIII* Implications of site-specific nutrient management in irrigated rice on future fertilizer use in Asia

Rice production in Asia was forecasted to increase by about 25% from 1999 to 2020 using the IMPACT model of the International Food Policy Research Institute (IFPRI). Based on this forecast, different scenarios were explored in a study to determine production requirements in irrigated rice for the given time period based on assumptions on harvest area and production growth on irrigated and non-irrigated rice land (Witt *et al.,* 2002). On average, required rice production on irrigated land in Asia would need to increase at an annual rate of about 1.25% from 406 Mio. t in 1999 to about 527 Mio. t by the year 2020. This would assume a slight increase in irrigated rice land of 0.15% yr$^{-1}$, so that yields would have to increase by 1.1% yr$^{-1}$ from about 5.3 t ha$^{-1}$ in 1999 to 6.7 t ha$^{-1}$ in 2020.

Using a large data set from on-farm experiments with irrigated rice in six Asian countries conducted between 1997 and 1999, fertilizer use, recovery efficiencies and indigenous nutrient supplies for N, P and K measured in farmers' fields were used as initial input parameters for 1999 to simulate fertilizer requirements until 2020 using a modification of the QUEFTS model (Janssen *et al.,* 1990). Two scenarios were evaluated with i) no changes in nutrient use efficiencies and a baseline growth in total fertilizer use of 1.1% yr$^{-1}$ comparable to the required growth rate in yield (scenario 1), and ii) annual increases in fertilizer rates of 0.55% for N, 0% for P and 4% for K, assuming efficient fertilizer use and balanced nutrition through site-specific nutrient management (SSNM) by 2020 (scenario 2). Model simulations and results from on-farm evaluation of SSNM suggest that future yield and production requirements are likely to be met, if farmers had access to improved nutrient management strategies while gradually improving the general crop management. Germplasm was assumed to improve at rates comparable to those of last 30 years. With scenario 1, only 90% of the targeted yield of 6.7 t ha$^{-1}$ could be achieved in 2020 so that production would fall short by 56 Mio. t because of inefficient use of fertilizer N and unbalanced fertilization ($N:P_2O_5:K_2O$ ratio of 6.3 : 1 : 0.75). In scenario 2, yield and production targets were met through proper N management and a $N:P_2O_5:K_2O$ ratio of 3.1 : 1 : 1.6 that would be required by the year 2020. Total fertilizer consumption in 2020 was similar for both scenarios but fertilizer K would have to increase at the expense of fertilizer N and P in scenario 2 (see Fig. 1). Data from on-farm testing of SSNM in 1997-2000 supported the simulation results showing increases in yield (+7%), profit (+55 US$ ha$^{-1}$ crop$^{-1}$), N recovery from applied fertilizer (+24%) and agronomic N use efficiencies (+29%) compared with the farmers' fertilizer practice (Dobermann *et al.,* 2004). Responses to additional fertilizer K were evaluated where required and yield increases ranged from 0.2-0.4 t ha$^{-1}$.

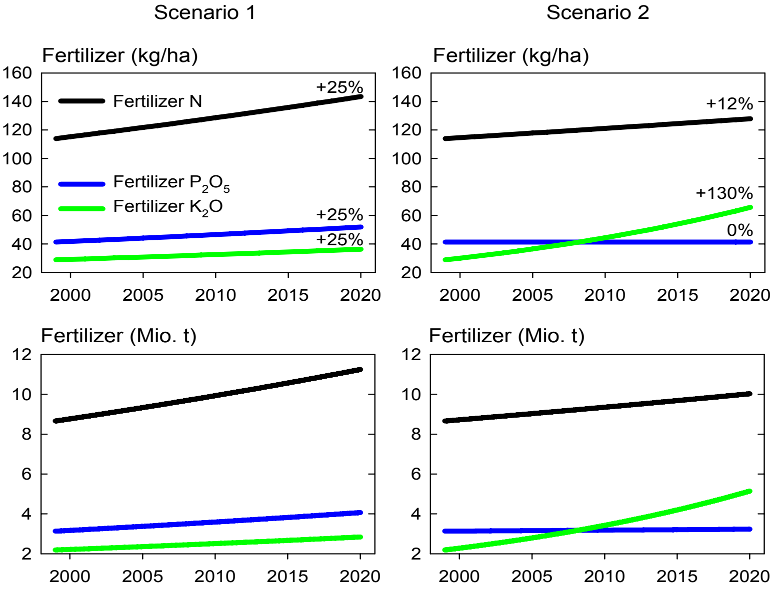


Fig. 1. Fertilizer requirements in Asia based on baseline growth in fertilizer use (scenario 1) and nutrient efficiency growth (Scenario 2) using the model QUEFTS (Witt et al., 2002).

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# Events

**IPI Coordinator, Dr. P. Imas presented a paper on "Nutritional management in rice for improving productivity in different regions in India" at the 2nd International Rice Congress 9-13 October 2006, New Delhi, India.**

Imas, P.[1], Singh, Y.[2]; Dhakshinamoorty, M.[3]; Misra, B.[4] and Bansal, S.K.[5]

[1] International Potash Institute, Switzerland - patricia.imas@iclfertilizers.com; [2] Department of Soils, Punjab Agricultural University, Ludhiana, Punjab, India; [3] Centre For Soil and Crop Management Studies, Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India; [4] Department of Soil Science, G.B. Pant University of Ag. & Tech (GBPUAT), Pantnagar, Uttranchal, India; [5] Potash Research Institute of India, Gurgaon, Haryana, India.


*Dr. P. Imas, IPI Coordinator India, presenting a paper at the 2nd International Rice Congress 2006, October 9-13, New Delhi, India.*

**Abstract:** Rice is the most important crop in India in terms of both area and fertilizer use. Rice cropping systems have been greatly intensified in India during the last decades to meet the increasing demand for food by the increasing population. Potassium (K) nutrition in rice is important because of its role in productivity and the large quantities of this macronutrient that are extracted by such intensive cropping systems. However, K application in rice in India is very low, both in absolute doses (13 kg/ha $K_2O$) and in the K:N ratio (0.15 units $K_2O$ used for each unit of nitrogen).

There is concern now that the increased crop yields and nutrient withdrawal, in combination with unbalanced fertilization, may lead to K depletion of the soil and to K deficiency in rice. This study was set-up to increase the understanding of K response in rice cropping systems.

Rice field experiments were conducted at three regions in India (Tamil Nadu, Punjab and Uttranchal) differing in their rice cropping systems and soil types. Graded K doses were combined with different nitrogen doses, application methods and/or crop residue management practices.

Potassium fertilizer application significantly enhanced both grain and straw yield of rice. The effect of K fertilization was found to be more significant at higher doses of nitrogen, when K application was split and residues were removed.

The results suggest that in years to come, K will be one of the most limiting factors affecting sustainability of rice systems in India. Therefore, due attention must be paid to K nutrition in fertilizer scheduling in rice, and balanced and efficient fertilizer management strategies have to be developed.

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**IPI-AFA 1st training course, Cairo, Egypt.** Dr. M. Rusan, IPI Coordinator WANA2 and Dr. S. Ashkar, Secretary General AFA opened the first training course (TC) on 'Balanced Fertilization' in Cairo, 26 August 2006. The TC was jointly organized by IPI and the Arab Fertilizer Association (AFA) with partnership of the Egyptian Union of Fertilizer Producers and Distributors. Some 60 farmers, engineers, marketing managers, company dealers, producers and distributors of fertilizers participated. The 2nd TC took place in Cairo this month. These events are an important milestone in the fruitful cooperation between IPI and AFA.

*Inauguration of the 1st IPI-AFA training course on Balanced Fertilization. (from left to right): Dr. Mustaf El-Fouly, consultant , Dr. Munir Rusan, IPI Coordinator WANA region, Dr. Shafik Al-Ashkar, Secretary General, AFA and Eng. Mohammad Al-Chechen, Board Chair of Al-Munofia Co.*

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**Fertbio 2006.** Dr. A. Naumov, IPI Coordinator Latin America, organized a Symposium on "Potash in Agricultural Systems of the Tropical Savannas of South America: Adequate Practices of Fertilization for Low Fertile Soils". This joint IPI-EMBRAPA symposium was held at the annual meeting of FERTBIO, a leading scientific event for soil science and plant nutrition in Brazil.


*The FERTBIO 2006 program.*

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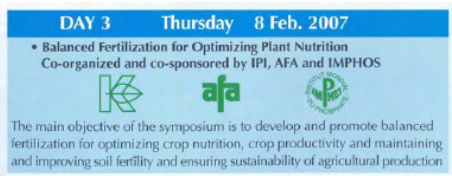
**8 February 2007, Sharm El Sheikh, Egypt:** The 1st joint IPI-AFA-IMPHOS workshop on 'Balanced Fertilization for Optimizing Crop Nutrition' will be held as a satellite event of the 13th AFA International Annual Fertilizer Conference. The main topics are:

- Potassium and phosphorus in balanced fertilization
- Nutrient management in irrigated crops
- Site specific nutrient management (SSNM)
- Current fertilizer use and nutrient balance in individual countries
- Research findings/results of crop response to balanced fertilization

For more details please contact Dr. M. Rusan, IPI Coordinator in WANA, at mrusan@just.edu.jo.

More details on the web at http://www.ipipotash.org/.




*AFA 13th International conference 6-8 February 2007 (http://www.afa.com.eg).*

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# New publications

**"The International Potash Institute and Agriculture Today"** This new leaflet describes IPI's mission, targets and activities. Ask the regional coordinator, or head office, for hard copies. Or you can download the leaflet from http://www.ipipotash.org/.

**Potassium – an important nutrient for sustainable production of quality cereals** (in Bulgarian) 2006. The leaflet describes the fundamentals of potassium fertilization in cereals. Available for download on our website. Please contact Dr. T. Popp, IPI Coordinator in Central Europe for copies.

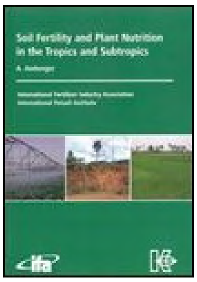
**The importance of potassium for nutrient supply of spice pepper** (in Hungarian) 2006. The leaflet describes the role of potassium fertilization in the production of spicy pepper. This publication is available for download on our website. Please contact Dr. T. Popp, IPI Coordinator in Central Europe for copies.

**Importance of balanced fertilization for sustainable crop production in the Czech & Slovak Republic** (in Czech and Slovaky) 2006. The booklet describes the approach of 'Balanced Fertilization' in typical crops of the Czech and Slovak republic. Check our website or contact Dr. T. Popp, IPI Coordinator in Central Europe for copies.

**Balanced Plant Nutrition in Viticulture for High Yield and Quality** (in Hungarian) 112 p. 2006. ISBN 963-85126-7-9. Proceedings of the symposium in Keckemét, Hungary, 6-7 September, 2005. Eds. I. Buzas and B. István, Institute of Environment Science, MOA, Hungary. The proceeding contain 10 papers and discusses the role of potassium in grapes, application methods of K fertilizers, K effect on different vine varieties, effect of rootstocks on transport of K and the effect of potassium and nitrogen on yield and quality of vines. Please contact Dr. T. Popp, IPI Coordinator in Central Europe for copies.

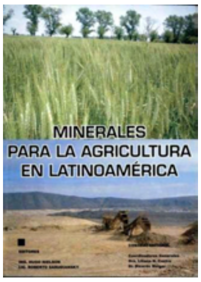
**Potash Facts in Brief** (in Arabic) 2006 10 p. Translated by Prof. M. Rusan. Printed jointly with the Arab Fertilizer Association (AFA), Cairo, Egypt. Copies available at IPI Head Office and at AFA, Cairo (www.afa.com.eg).

**Potassium dynamics in the soil** (in Arabic) 10 p. 2006. Translated by Prof. M. Rusan. Printed jointly with the Arab Fertilizer Association (AFA), Cairo, Egypt. Copies available at IPI Head Office and at AFA, Cairo (www.afa.com.eg).



**Soil Fertility and Plant Nutrition in the Tropics and Subtropics.** 96 p. 2006. ISBN 2-9523139-0-3. Published jointly by the International Fertilizer Industry Association (IFA) and the International Potash Institute (IPI), this book discusses the possibilities and constraints in food production on the many different soil types found in tropical and subtropical countries. By indicating ways in which crop nutrition and hence crop production can be increased on these soils in developing countries, the author shows ways to ensure food security and improve livelihoods.

Professor Dr. A. Amberger has had extensive experience in the tropics and subtropics, coordinating and organizing agricultural research programmes and serving as a consultant to international organizations. The topics discussed in this book are a synthesis of Professor Amberger's considerable experience and testimony to his many years of collaborative scientific work. The text is based largely on his lectures to students at the Technical University of Munich. For more details see our web site.




**Minerales para la Agricultura en Latinoamérica** (in Spanish) 574 p. 2005. ISBN 987-22647-0-8. Eds. H. Nielson and R. Sarudiansky. Latin America consumes nearly 25 million tons of fertilizers per year, a figure that grows steadily supporting the agricultural development of the region. In spite the dynamic installed capacity of the industry and local mining, the region is a net importer of nearly 4 million tons of products, mainly phosphates and potassium.

Various mining resources in the region are being rediscovered and old projects are now become profitable again in several countries.

This book represents a concerted effort of integration between geologists and agronomists in Latin American countries. Project CYTED (http://www.cyted.org) achieved this important work by recovering information and making it available to users. For copy, please contact Dr. R. Melgar, INTA, Estacion Experimental Agropecuaria Pergamino, C.C.31, C.P. 2700 Pergamino, Provincia de Buenos Aires, Argentina (rmelgar@pergamino.inta.gov.ar).

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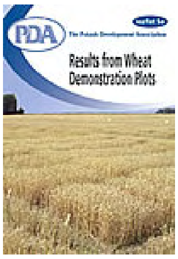
# Publications by the PDA

What is the PDA (Potash Development Association)?

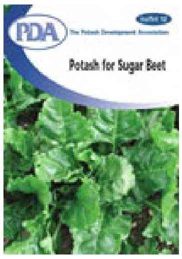
The Potash Development Association is an independent organisation formed in 1984 to provide technical information and advice in the UK on soil fertility, plant nutrition and fertilizer use with particular emphasis on potash. See also http://www.pda.org.uk/.

Note: Hardcopies of PDA's publications are available only in the UK and Ireland.




#5a. Results from Wheat Demonstration Plots

Crops of wheat were grown on small unreplicated plots in the Arable Area of the National Agricultural Centre, Stoneleigh. The same treatments were used on the same plots for each of the 4 years; 1987-1990. Soil was sampled in the autumn before the first harvest year and in each autumn of the comparison. See PDA website.




#12. Potash for Sugar beet

During the last 20 years yields of clean beet and sugar in the UK have been increasing linearly, at an average annual rate of 0.48 tonnes per hectare of beet and 0.01 t/ha sugar. Now the aim is to increase the average yield….. See PDA website.

# K in the literature

**Mineralogical budgeting of potassium in soil: A basis for understanding standard measures of reserve potassium**. Andrist-Rangel, Y.; Simonsson, M.; Andersson, S.; Öborn, I. and S. Hillier. J. Plant Nutr. Soil Sci. 169:5, pp 605-616 (2006). (http://www3.interscience.wiley.com/cgi-bin/jhome/10008342)

**Abstract**: The study was conducted to investigate the relationship between some standard measures of soil reserve potassium (K) and soil mineralogy. Eight different agricultural soils from the N temperate and S boreal regions were studied and analyzed both by standard methods (exchangeable K, 2 M HCl and aqua regia-extractable K) and by quantitative mineralogical methods based on X-ray powder diffraction analysis of spray-dried bulk soils. Linear regression and multivariate methods were used to assess the relationships between standard measures of soil reserve K and a number of soil chemical, physical, and mineralogical properties. A mineralogical budgeting approach, to estimate total K and its speciation between different mineral phases, is shown to be accurate after validation against total K analyzed geochemically. This approach enabled us to determine that both HCl and aqua regia-extractable K were highly correlated with K in dioctahedral phyllosilicates and extracted 1%-17% and 5%-45% of total K, respectively. Neither extraction showed any obvious relationship to K in feldspar, which is frequently a larger reservoir of K in the soils examined.

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**Effect of Long-term Integrated Nutrient Supply on Soil Chemical Properties, Nutrient Uptake and Yield of Rice.** Reddy, M..D., Rama Lakshmi, CH.S., Rao, C.N., Rao, K.V., Sitaramayya, M., Padmaja, P and T. Raja Lakshmi. Indian J. of Fertilizers Vol. 2(2), May 2006, pp. 25-28.

**Abstract**: An experiment on long-term integrated nutrient supply in rice-rice cropping system was conducted for 31 seasons during Kharif and Rabi from 1988 to 2003-04 under irrigated conditions. After 31 seasons of rice cropping, there was an increase in organic carbon from 0.54 to 0.63% and available P from 15 to 20 kg/ha in treatments that received organic and chemical nutrition and 18 kg/ha with continuous application of recommended dose of fertiliser over initial available P status (24.4 kg/ha). There was an increase of 25 kg/ha (RD) of K with 100% RD NPK fertiliser and 17 to 27 kg/ha of K with application of 50 to 75% of RD along with 25 to 50% of RD N through organic source. On the other hand, there was a decrease of 55 kg/ha K without application of any nutrients and 4-14 kg of K decrease with 50-75% of RD NPK fertiliser over the initial value. From the beginning of experiment (1988-89), combination of NPK with organic manures recorded higher grain yield in a year (8.83 to 11.95 t/ha). Highest sustainable yield index (54.85% in Kharif and 47.38% in Rabi) was observed with 100% RD of NPK alone. The highest N, P and K uptake was recorded with application of 50% RD NPK+ 50% N through glyricidia.

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**Effect of potassium nutrition on growth, yield and quality of papaya (Carica papaya L.)** Kumar, N.; Meenakshi, N., Suresh, J. and V. Nosov. Indian J. of Fertilizers 2(4): 43-47 (2006).

**Abstract**:An experiment was conducted in Tamil Nadu at four locations in farmers' fields to study the effect of K nutrition on growth, yield and quality of fruits and latex during 2004-05 in randomised block design with three replications and four treatment combinations (300:300:0; 300:300:150; 300:300:300 and 300:300:450g N:$P_2O_5$:$K_2O$/plant/year). The study showed that growth characters like leaf number were significantly influenced by K nutrition at two locations and leaf area at one location. The yield and yield attributing characters showed under the treatment K300 were significantly higher as compared to other treatments. The quality characters viz., TSS, pulp thickness and cavity index increased with increase in K levels except for acidity. With respect to yield of latex no definite trend could be observed with K nutrition but the quality of latex was influenced with K nutrition. The leaf nutrient content was also increased significantly with increase in K nutrition levels.

Magnesium (Mg) is known as one of the essential nutrients for higher plants. The work of Ding *et al.*, (Annals of Applied Biology, 2006, 149, 111-126) shows that Mg deficiency in rice, resulted in significant reduction in shoot biomass, decrease in total chlorophyll concentration and net photosynthetic rate and reduction in activities of both nitrate reductase and glutamine synthetase. The authors show that there were great antagonistic and moderately synergistic effects between K and Mg, but the effects of K on soluble sugars uptake and translocation, as well as nitrate reductase activity and net photosynthetic rate in the leaves were much more significant than those of Mg.

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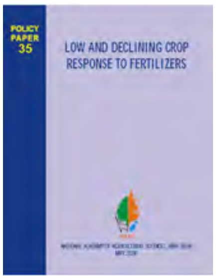
For more K literature go to www.ipipotash.org/literature/.

# K for thought

## Evidence of declining productivity in cereals in India: A source for concern

The reduced response of foodgrain production to fertilizer application is now widely observed in many parts of India. To address this issue, a two-day brain storming session on "Low and Declining Response of Crops to Fertilizers" was organized by the National Academy of Agricultural Sciences (NAAS), India and held in New Delhi, India (20-21st February, 2006).




This concise policy paper first describes the background of reduced foodgrain production and outlines the main causes for "Low and Declining Crop Response to Fertilizers". Among these, inadequate P and K application which leads to soil mining is placed high on the list. At the section that describes the required agenda for research, nutrient budgeting and precise site specific fertilizer recommendations and application are highly graded. The role of extension is highlighted with an array of action items that needs to be implemented. Finally, various policy actions are recommended.

It is interesting to note that this policy paper also emphasizes the need to increase productivity through balanced fertilization of macro and micro nutrients in order to achieve higher nutrient use efficiency, especially that of N. Yet, negative K balance is widespread in many countries. Ladha *et al*., (2003) reported that as many as 94% of the long term experiments in Asia were showing negative balance for potassium, 50% with a deficit of more than 100 kg $K_2O$/ha pa. Moreover, all the long term experiments that demonstrated yield decline had large negative K balance.

Balanced fertilization, coupled with precise fertilizer recommendations based on soil and plant analysis, has great potential to restore productivity and decrease inputs and the risk to the environment.

### References

NAAS. 2006. Low and Declining Crop Response to Fertilizers. Policy Paper No. 35, National Academy of Agricultural Sciences, New Delhi. pp 8.

Ladha, J.K., Hill, J.E and J.M. Duxbury (eds.). 2003. Improving the Productivity and Sustainability of Rice-Wheat Systems: Issues and Impacts. ASA, IRRI, CIMMYT. ASA special publication 65 (data adapted from page 63-64).

## Biofuels — and the energy cost of nutrients

The cost of producing biofuels vary greatly between the various sources. For example, production cost of fuel from sugarcane in Brazil costs only 16 U.S. cent/litre, from cassava in Thailand it costs 26 U.S. cent/ litre and from maize and wheat in the US and Europe it costs 30 and 55 U.S. cent/ litre, respectively. At the time of this analysis, the price of 1 litre petroleum was 59 U.S. cent, making all the sources of bioethanol cost effective in various degrees (von Brown, 2005, citing Henniges and the European Commission in 2005).

In addition to the total cost of producing bioethanol, the energy balance for growing, harvesting and processing of each biofuels crop is extremely important. In this respect, the energy cost of the fertilizers, among other inputs, has to be taken into account.

Potassium fertilizers mined from underground mines or produced in evaporation ponds have a low energy demand as compared to other macro nutrients. With continuous strong demand for biofuels and supporting policies adopted in many countries, the various aspects of effective fertilization of biofuel crops will probably be high on the agenda.

### Reference

von Brown, 2005. The world food situation, an overview. A paper Prepared for CGIAR Annual General Meeting, Marrakech, Morocco, December 6, 2005.

# Clip board

- Subscribe to receive this *e-ifc* electronically at e-ifc-subscribe@ipipotash.org.
- During 2007 we will cover research done on nutrient management in oil palm and maize in South East Asia and bring in results from field experiments in India, Central Europe and more.
- We are now scanning old IPI publications and make them available on our website. Oldies but goldies.
- Season's Greetings to all our readers!

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