Better Crops International

Vol. 16, No. 2
November 2002

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BCI is intended primarily for agricultural leaders and scientists working in agronomy and related sciences outside North America. Subscription price is (U.S.) $5.00 (five dollars) per year (free on request to qualified individuals).

The Government of Saskatchewan helps make this publication possible through its resource tax funding. We thank them for their support of this important educational project.

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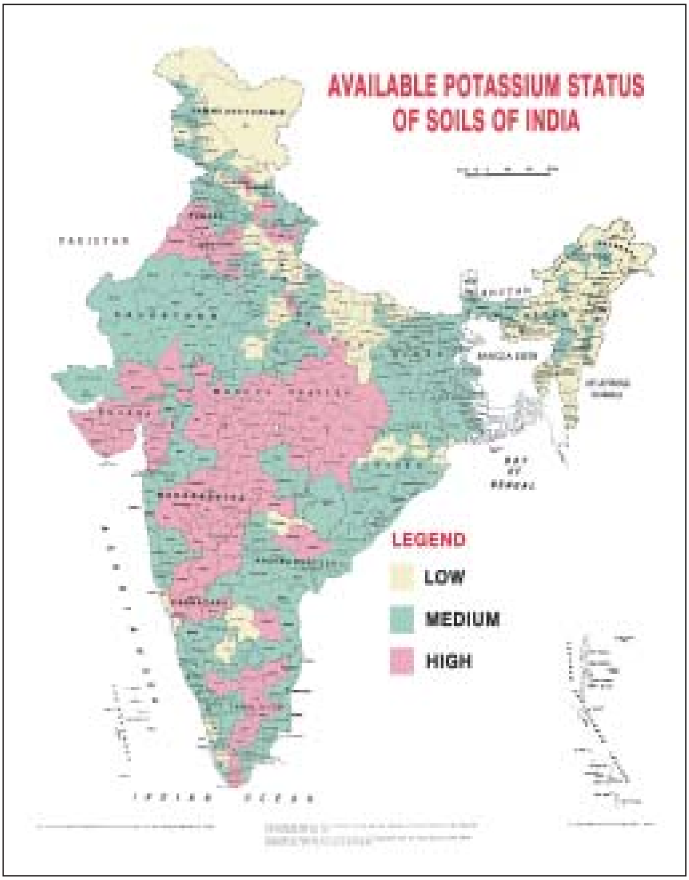
Potassium Status of Soils in India

By Rehanul Hasan

Soil test results for potassium (K) fertility status among India's agricultural soils are categorized accordingly: 21% low, 51% medium, and 28% high. Thus, 72% of India's agricultural area, representing 266 districts, needs immediate K fertilization.

Soils rated as high can show significant responses to applied K in certain soil, crop, and climatic situations. Thus, soil test methods for categorizing soils into low, medium, and high K values need further refinement for better soil test/crop response correlation. A serious attitude towards K application is still lacking among farmers and extension workers. There is an urgent need to educate both about the importance of K in Indian agriculture for nutrient balance and efficiency, top crop yields and quality, and farmer profitability.

Figure 1. Nutrient index values for India indicate that 21% of districts are low, 51% are medium, and 28% are high in K fertility.



Since the arrival of high-yielding varieties (HYVs) of foodgrains in the 1960s, tremendous progress has been made in fertilizer use and agricultural production. Higher production of food, fibre, and other crops also results in much higher removal of nutrients from soils. Clearly, expansion in fertilizer application (input) continues to fall short of nutrient removal (output), resulting in depletion of soil fertility and negative nutrient balance. The situation cannot go on forever and strikes at the very root of sustainable agriculture.

Potassium is one of the three main pillars of balanced fertilizer use, along with nitrogen (N) and phosphorus (P). While India is the third largest

Table 1. Number of districts categorized as having low, medium, and high K-fertility status.

State	Low	Medium	High
Andhra Pradesh	2	14	3
Arunachal Pradesh	2	3	0
Assam	7	3	0
Bihar & Jharkhand	1	24	2
Chandigarh	0	1	0
Dadra & Nagar Haveli	0	1	0
Delhi	0	1	0
Goa	1	0	0
Gujarat	0	3	16
Haryana	0	2	9
Himachal Pradesh	6	4	3
Jammu and Kashmir	5	5	0
Karnataka	3	10	7
Kerala	4	6	0
Madhya Pradesh & Chhatisgarh	3	10	31
Maharashtra	0	12	13
Manipur	1	0	0
Meghalaya	1	0	0
Mizoram	1	0	0
Nagaland	5	0	0
Orissa	2	11	0
Punjab	0	9	3
Pondicherry	1	0	0
Rajasthan	0	23	3
Sikkim	0	4	0
Tamil Nadu	0	6	7
Tripura	3	0	0
Uttar Pradesh & Uttaranchal	26	23	7
West Bengal	2	13	1
Total districts, (%)	**76 (21)**	**190 (51)**	**105 (28)**

user of NPK fertilizers in the world, with current annual consumption at about 18 million tonnes (M t) of N + P_2O_5 + K_2O, K constitutes only one-seventh of the total.

Higher crop K requirement comes with higher crop yields. Potassium's importance in plant growth and development has been known for over 150 years. Most crops take up as much or more K than N. About 70 to 75% of the K absorbed is retained by leaves, straw, and stover. The remainder is found in harvested portions such as grains, fruits, nuts, etc. Whenever the soil cannot adequately supply the K required to produce high yields, farmers must supplement soil reserves with fertilizer K. It is necessary to continually emphasize the role and importance of K in crop production as balanced fertilizer use has a direct bearing on the country's capability to produce its ever-increasing requirement of food, fibre, and other farm-based commodities. Improvements in both quantity and quality will add to export earnings.

Information presented here is based on more than 11 M soil samples made available by soil testing laboratories run by state departments of agriculture and the fertilizer industry. Part of the data originates from technical reports published by state departments of agriculture and publications appearing in scientific journals during the last two decades. Though 11 M soil tests are not sufficient to comprehensively cover a country which has more than 140 M cultivated ha, they reflect changing K fertility status of soils in different parts of the country and provide some measure of need for scientific use of K fertilizers.

Available soil K was extracted with 1N ammonium acetate (NH_4OAc, pH 7.0) and soils containing less than 130 kg K_2O/ha were categorized as low, between 130 and 335 kg K_2O/ha as medium, and above 335 kg K_2O/ha as high. State-by-state available K status is given in **Table 1.** The map and distribution of districts considered low, medium, and high in K fertility (**Figure 1**) show that out of 371 districts for which information is available, the respective number of districts characterized as low, medium, and high are 76, 190, and 105, respectively. Thus, 21% of the districts are low, 51% are medium, and 28% are high, using the nutrient index values suggested by Ramamurthy and Bajaj (1969). (A complete listing of districts in low, medium, and high categories is available but not included here.)

Comparing these results with those presented earlier by Ghosh and Hasan (1980), the low and high categories have decreased by 0.6 and 6.4%, respectively, while the medium category increased by 7%. All this indicates that K fertilizers were scantily applied in the last two decades as the low category has virtually remained the same and the high area has fallen.

Lack of farmer awareness about the importance of K indicates need for more education. For example, farmers may not realize the effect of applied K on the size, shape, color, and quality of produce at maturity, so its need may be overlooked. In contrast, the benefits from N and P are more readily apparent from initial stages of crop growth. Another reason for inadequate use of K fertilizers may be the lack of crop response to applied K, even on low K testing soils. However, significant responses to applied K may be noted in high K soils. To overcome such anomalies, intensive research is needed at national and state levels to consider total K, exchangeable and non-exchangeable K, and K-fixing capacity of the soils under different soil-crop-climatic conditions.

An increasing number of farmers throughout India want to produce top yields and high net returns. Understanding soil nutrient status and corrective fertilizer management practices to support high yields of high quality crops requires a continuation of scientific information and broadly based education programs for the farm advisory service, soil and plant testing laboratories, trainers, the mass media, and ultimately the farmer. **BCI**

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Acknowledgments

The author gratefully acknowledges the cooperation rendered by the officer in-charge of soil testing laboratories in the country, directors of agriculture in the states, vice-chancellors, heads of departments of soil science and agricultural chemistry of the state agricultural universities, and the fertilizer industry. Thanks also to past and present directors of IARI for their encouragement of this publication and the soil fertility map of the country, and to colleagues at IARI and PPIC for their help and constructive suggestions.

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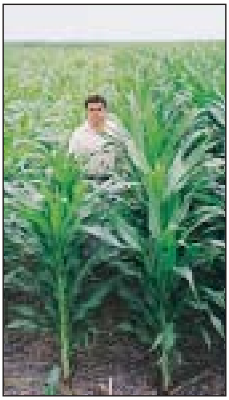
Corn Fertilization in the North Central Pampas: CREA Experiments South of Santa Fe

By Alejandro Thomas, Miguel Boxler, Belisario Alvarez de Toledo, Raúl Houssay, Luciano Martín, Angel Berardo, and Fernando O. García

On-farm research conducted in southern Sante Fe and Cordoba provinces is explaining crop responsiveness to applied nutrients. Expectations for corn yield gains resulting from macronutrients and micronutrients are outlined. A preliminary critical soil sulfate-sulfur (SO_4^{2-}-S) value for the region's corn crop is suggested.

Nutrient management in corn has been evaluated in different soils of the Pampas, and nitrogen (N) and phosphorus (P) fertilization recommendations have been developed (Berardo et al., 2001; González Montaner and Di Napoli, 1997a,b; Sainz Rozas et al., 2000; Ruiz et al., 2001). Corn N fertilization is determined according to soil nitrate-N (NO_3^--N) availability at planting (Ruiz et al., 2001), whereas P fertilization is based on soil and crop criteria developed in the southern area of the Pampas (Berardo et al., 2001). There is a lack of criteria for S fertilization in the region. However, in recent years, S deficiencies and responses to S fertilization have been observed in corn and other annual crops in the northern area (Cordone et al., 2001).



At La Marta, Miguel Boxler stands between the check plot (left) and the NPS plot.

For the Regional Consortium of Agricultural Experimentation (CREA) region south of Santa Fe, the area planted to corn accounts for approximately 39,800 ha of the 184,500 ha in annual crops every year. The CREA region south of Santa Fe is comprised of 12 groups of 10 to 15 farmers, located in southern Santa Fe and Cordoba provinces, with the goal of developing and exchanging experiences and information on soil and crop management, farm business management, and product marketing. A network of fertilization trials was established in the 2000/01 growing season to: 1) evaluate corn response to applied N, P, S, and other nutrients such as potassium (K), magnesium (Mg), boron (B), copper (Cu), and zinc (Zn); 2) validate N and P fertilization recommendation methods; and 3) evaluate the soil SO_4^{2-}-S test for S fertilization recommendation.

Eight on-farm trials were conducted by different CREA groups in 2000/01. Test soils were Argiudolls (eastern area) and Hapludolls (western area). All sites were under no-tillage management. Corn *cv.* Monsanto

Table 1. Fertilizer treatments applied to CREA on-farm trials, 2000-01.

Treatment	Application rates, kg/ha
Control	———
PS	20 kg P + 19 kg S
NS	100 kg N + 19 kg S
NP	100 kg N + 20 kg P
NPS	100 kg N + 20 kg P + 19 kg S
Complete	NPS + 18 kg K + 10 kg Mg + 1 kg B + 2 kg Cu + 4 kg Zn

DK 696 MG was planted between September 18 and October 13 at a 70 cm row spacing. Fertilizer treatments (kg/ha) were assigned to a randomized complete block with three replications (**Table 1**). All fertilizers were banded below and to the side of the seed at planting. At maturity, grain yield (14.5% moisture content) was determined by harvesting an area of 180 to 360 m^2.

Soil samples were taken from each experimental site prior to planting to determine soil organic matter, pH, Bray P-1, exchangeable calcium (Ca), Mg, K, and micronutrient concentrations [Cu, Zn, iron (Fe), and manganese (Mn)] at 0 to 20 cm depth; and NO_3^--N, SO_4^{2-}-S, and borate-B ($H_2BO_3^-$-B) at 0 to 20, 20 to 40, and 40 to 60 cm depth. Soil NO_3^--N concentration at 0 to 30 cm was also determined at V5-6 (Ritchie and Hanway, 1982) in the PS treatment. Chlorophyll meter readings (Minolta SPAD 502) were determined at V5-6 and R1 in treatments PS and NPS.

Results

Soil analysis. Soil organic matter levels and pH were within the normal ranges for soils of the region (data not shown). Nitrate-N availability at planting was generally low (< 150 kg/ha NO_3^--N, 0 to 60 cm), except at San Antonio where levels were 304 kg/ha. Bray P-1 concentrations were low [< 15 parts per million (ppm) P] at Balducchi, San Antonio, La Marta, and El Pilarcito, medium (15 to 25 ppm P) at La Blanca and Santo Domingo, and high (> 25 ppm P) at San Alfredo and Lambaré. Sulfate-S availability (0 to 20 cm depth) was low (<10 ppm) at four sites, and medium (10 to 15 ppm) at four sites. Concentrations of other nutrients were considered adequate for corn production according to international references.

Soil NO_3^--N concentrations at V5-6 (0 to 30 cm) were very low (< 12 ppm) at all sites because of plant growth and high precipitation between planting and V5-6 that leached the majority of NO_3^- from the 0 to 30 cm layer.

Corn grain yields and response to fertilizers. Abundant precipitation in October, November, and January reduced incidences of moisture stress and helped to produce high corn yields. Control yields varied from 5,630 kg/ha (Balducchi) to 9,680 kg/ha (Lambaré), while maximum yields from the fertilized treatments varied from 8,090 kg/ha (San Antonio) to 12,300 kg/ha (San Alfredo) (**Table 2**). All sites, except San Antonio, showed statistically significant differences in corn yields among treatments. The low yields and lack of response at San Antonio is not readily explainable, but are partly attributed to high soil NO_3^- -N availability at planting (which improved the control yield) and soil degradation due to compaction.

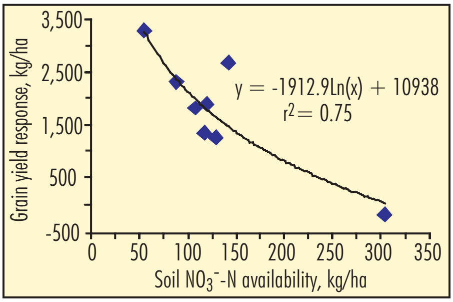
Table 2. Corn grain yields for the six fertilization treatments in the eight experimental sites.

	Corn grain yields, kg/ha							
Treatments	La Blanca	Balducchi	San Antonio	Lambaré	Santo Domingo	La Marta	El Pilarcito	San Alfredo
Control	7,070 b[1]	5,630 b	7,690	9,680 c	7,840 b	9,080 c	6,350 c	8,280 d
PS	8,110 ab	6,090 b	7,970	10,600 b	7,560 b	10,300 bc	6,380 c	8,780 d
NS	9,000 a	7,970 a	8,090	11,800 a	9,410 a	11,100 ab	8,820 b	9,960 c
NP	8,910 a	8,090 a	7,850	11,900 a	9,410 a	12,000 a	8,760 b	10,800 bc
NPS	9,360 a	8,400 a	7,740	12,000 a	9,450 a	12,100 a	9,680 ab	11,500 ab
Complete	9,180 a	8,370 a	7,880	11,700 a	9,630 a	11,200 ab	10,000 a	12,300 a
LSD, 5%	1,450[2]	1,200	ns[3]	806	548	1,200	1,060	1,130

[1] Grain yields followed by different letters in a same column are significantly different at the 5% probability level. [2] Differences significant at the 10% probability level. [3] ns = No significant differences.

Corn yield response to N (NPS vs. PS) was significant at six of the eight sites, whereas the P response (NPS vs. NS) was significant at only one site (San Alfredo). Four sites showed tendencies to P response (La Marta, El Pilarcito, Balducchi, and La Blanca), and to S response (NPS vs. NP; El Pilarcito, San Alfredo, La Blanca, and Balducchi). There were no significant differences between the NPS and complete treatments, indicating that the availability of soil K, Mg, B, Cu, and Zn was sufficient for these grain yields when moisture was generally sufficient throughout the growing season.

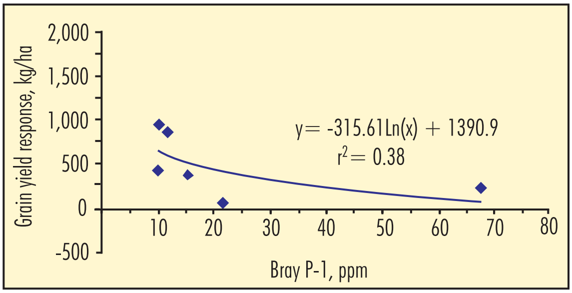
Figure 1. Corn yield response to N as a function of soil NO_3^--N availability at planting, 0 to 60 cm depth.



Relationships among soil and plant variables and response to fertilizer. Nitrogen response was significantly related to soil NO_3^--N availability at the 0 to 60 cm depth (**Figure 1**). Previous research in northern Buenos Aires and southern Santa Fe provinces estimate the critical level to be 150 kg/ha NO_3^--N for corn grain yields of 9,000 kg/ha (Ruiz et al., 2001). The N response equation derived from these data (**Figure 1**) indicates an N response of 1,350 kg corn/ha for 150 kg N/ha of available soil NO_3^--N. The high N response may partly explain the high grain yields obtained. It should be cautioned, however, that a lack of test soils between 129 and 300 kg soil NO_3^--N/ha may be over emphasizing the influence of the site with the highest N fertility.

No relationship was found between N response and soil NO_3^--N concentration at V5-6, or chlorophyll meter readings at V5-6 (data not shown).

Figure 2. Corn yield response to P as a function of soil Bray P-1 at planting, 0 to 20 cm depth. The points belonging to the sites San Alfredo and San Antonio were omitted.



Grain yield response to P fertilizer was related to Bray P-1 levels except at San Alfredo and San Antonio (**Figure 2**). At San Alfredo, there was a high P response although the soil was high in available soil P (28 ppm Bray P-1). It is possible that the site's general low soil P status was not detected due to variability caused by previously applied P fertilizer bands under no-tillage.

The four sites with a tendency for S response had soil SO_4^{2-}-S levels lower than 10 ppm at 0 to 20 cm (**Figure 3**). This level may serve as a preliminary critical S level to decide S fertilizer requirements in the region. Soil SO_4^{2-}-S determination to the 60 cm depth did not improve the estimation of a critical level.

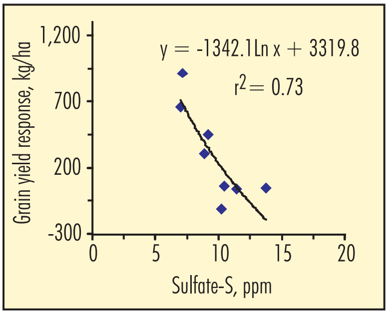


Figure 3. Corn yield response to S as a function of soil SO_4^{2-}-S concentration at planting, 0 to 20 cm depth.

Conclusions

Responses to N were significant in six of eight sites and were related to soil NO_3^--N availability at planting. Phosphorus response was significant at only one site and it was related to Bray P-1 levels. Responses to S were not significant, but a preliminary critical level of 10 ppm SO_4^{2-}-S is suggested. Application of K, Mg, B, Cu, and Zn did not affect grain yields at any site. **BCI**

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Acknowledgments

To the owners and personnel of the farms where the experiments were established. To Agroservicios Pampeanos (ASP) *for the support of this project and to* Monsanto Argentina *for its collaboration.*

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Aerial Fertilization of Oil Palm

By J.P. Caliman, Elikson Togatorop, Budi Martha, and R. Samosir

Today's technology is allowing for significant improvements in techniques associated with aerial fertilization. This article outlines the economic and nutrient efficiencies gained in an oil palm plantation currently operating a successful aerial fertilization program.

The dramatic expansion of the area planted to oil palm over the past 15 years has resulted in the development and reclamation of much marginal land, including peat soils and steeply sloping land. In some of these areas, in-field mechanization using ground vehicles is not possible because of steep slopes or poor drainage, or unacceptable soil and land damage caused by vehicles. Suitable areas for oil palm have been developed in remote locations where manpower is in short supply and it is difficult to maintain high standards of manual fertilizer application.

The oil palm requires large amounts of mineral fertilizer (500 to 1,000 kg/ha), usually carried into the field by hand or with a wheelbarrow. Each palm must receive the specified amount of fertilizer, usually applied by workers using calibrated containers to deliver the required amount to each tree. Poor supervision is one reason why fertilizer is often not applied properly and the application rate is reduced in the parts of the field most distant from the roadside. This results in spatial variability in the incidence of deficiency symptoms (as shown in the photo) and reduced yield and profitability. A second problem is fertilizer pilfering, due to the wide ratio between the value of fertilizer and the cost of labor.

For immature palms, fertilizers are best applied within the drip circle because root development is quite limited during the first three years after field planting. In contrast, roots under mature palms branch throughout the entire soil volume to a depth of 40 to 70 cm. It is therefore not surprising that only small differences in yield were detected between treatments that compared the application of fertilizer over the soil in weeded palm circles with fertilizer broadcast over the inter row (Foster and Dolmat, 1986). Some older work showed that the loss of fertilizer nutrients by leaching is reduced when fertilizers are applied over a larger surface area (Ochs, 1965).

Mechanical fertilizer application using ground vehicles in mature plantations meets

Patches of light-coloured palms in the middle part of fields are caused by uneven manual fertilizer application.

Photo source: PPI/PPIC ESEAP

Table 1. Compatibility of fertilizer used in oil palm .

	Ammonium nitrate	Urea	Triple superphosphate	Diammonium phosphate	Rock phosphate	Potassium chloride	Kieserite
Ammonium sulfate	🟥	🟨	🟩	🟩	🟩	🟩	🟩
Ammonium nitrate		🟥	🟨	🟩	🟩	🟨	🟩
Urea			🟥	🟩	🟩	🟨	🟨
Triple superphosphate				🟨	🟩	🟩	🟩
Diammonium phosphate					🟩	🟩	🟩
Rock phosphate						🟩	🟩
Potassium chloride							🟩

🟥	Incompatible
🟨	Limited compatibility[1]
🟩	Compatible

[1] Denotes mix just before application

Source: International Fertilizer Industry Association, 1992

most requirements in terms of even fertilizer application within fields, reduced labour requirements, and rapid application. Tractor-mounted spreaders can be used conveniently on flat mineral soils, but aerial fertilizer application is the only possible means for mechanical fertilizer application on peat soils and steeply sloping land where the cost of preparing the field for tractor access is too great.

Aerial fertilizer application has been used for years in the U.S., Australia, and New Zealand, but the first commercial trials for aerial fertilizer application in oil palm were implemented by FELDA in Malaysia (Wood et al., 1973; Tan et al., 1977; Lee, 1977). Several types of agricultural aircraft have been tested, with carrying capacities ranging from 800 to 1,000 kg. Some of the present models of agricultural aircraft have a capacity of 2,000 kg.

The main infrastructure requirement for aerial fertilizer application is a landing strip (one for every 3,000 to 5,000 ha), equipped with two fertilizer bins with capacity of 70 tonnes (t) each, for fertilizer loading and mixing. Equipment required for aerial fertilizer application includes the following: aircraft, loader, Global Positioning System (GPS), portable blender, and weighing equipment. A cement truck can be used to mix two or more fertilizers together to increase the rate of application and improve the efficiency of operation. A special loader, equipped with a hydraulic or cell weight gauge, provides sufficiently accurate records of the quantity of fertilizer applied.

Fertilizers that are to be mixed must be compatible in terms of physical and chemical properties (**Table 1**). Chemically compatible fertilizers may be mixed together without gaseous losses, decrease in nutrient availability, or caking due to chemical reactions. Physically compatible fertilizers have similar granule sizes and density so that segregation does not occur during transport (International Fertilizer Industry Association, 1992).

Fertilizer can be transferred to the agricultural aircraft using a loader.

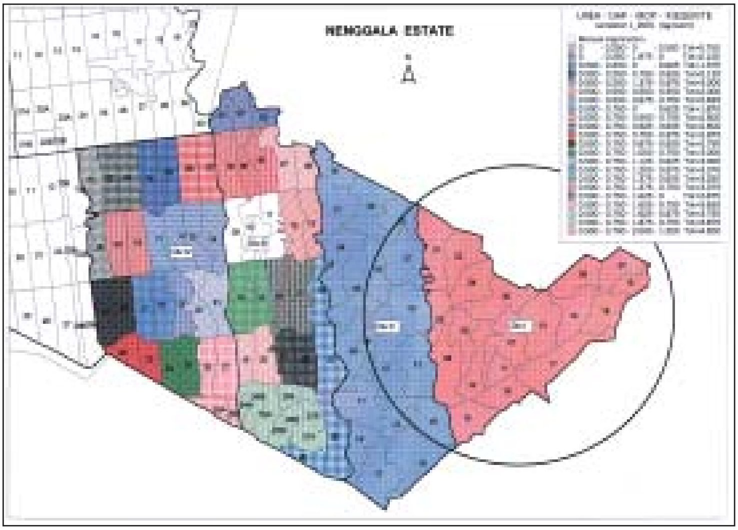


Figure 1. Fertilizer is applied by airplane in Division I and II where topography makes manual fertilizer application difficult and inefficient.

Geographic Information System (GIS) software is used to prepare maps showing the required application rate of fertilizer for each single estate field (**Figure 1**). These maps are required by the pilot to prepare a work program, and are more useful than tables showing fertilizer recommendations. Development of Differential Global Positioning Systems (DGPS) and related software for track guidance has replaced the use of ground flags to direct the aircraft. The system also provides a computerized record of each flight path including all the flight characteristics (swath, height, and speed) required for accurate fertilizer application mapping (**Figure 2**).

There are several advantages associated with aerial application. Fertilizers are evenly applied over the target area. Lateral distribution can be mastered by adjusting the swath width based on test runs where fertilizer is applied in an open area. A simple mathematical model can be fitted for each type of fertilizer, depending mostly on its specific guide number and uniformity index. Possibility of fertilizer theft is greatly reduced. Minimal field supervision is required because fertilizer is delivered to the airstrip bin. Application of fertilizer is supervised by reference to the aircraft's tracking record and through periodic checks in the field. The computerized recording system, together with the DGPS tracking guidance system, provide full performance accountability, as well as automatic and accurate guidance for the pilot to fly in parallel application lines. The amount of fertilizer applied is monitored using the weigh gauge fitted to the loading system. A fertilizer program can be completed in a shorter time compared with manual application. This may reduce losses as the timing of fertilizer application can be adjusted to local weather patterns.

By introducing aerial fertilizer application, workers are spared for specialized and highly paid tasks (e.g., harvesting) that have not yet been mechanized. This is very important in remote areas where manpower is scarce, or on steep terrain where manual fertilizer application is difficult to supervise.

Aerial application of fertilizer, properly done, does not have any adverse impact. Continuous monitoring of surface water and groundwater has shown that nutrient losses are small (Satyoso et al., 1997; Liwang et al., 2000) partly because a smaller amount of nutrient is applied per square meter, and thus nutrient losses due to leaching and

Figure 2. Computer printout showing airplane tracking details (left) and proportion of ground covered (right). The pilot has achieved good ground coverage using GPS.

surface run-off are reduced (Ochs, 1965).

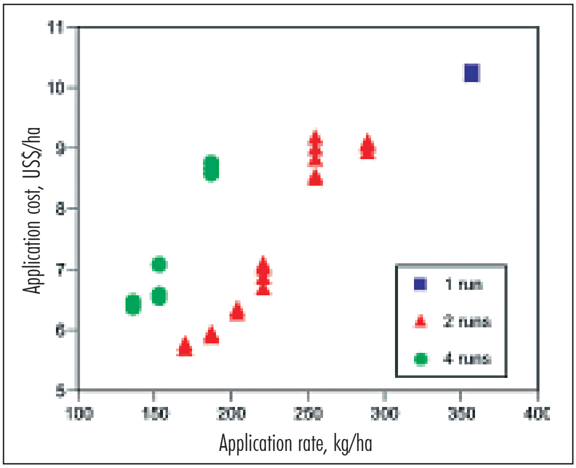
Several factors are critical for successful aerial application. The entire fertilizer procurement process must be coordinated with the field application program. The physical quality of fertilizer materials must be optimized to ensure uniform distribution over the field. Quality granular fertilizers (e.g., urea, diammonium phosphate, potassium chloride) should be used. Blending must be monitored closely when two or more fertilizers are applied at the same time. Fuel and oil delivery and the provision of spare parts must be organized, thereby avoiding costly aircraft downtime. Administrative requirements for the pilot, aircraft, and airstrip, as well as flight authorization must be arranged.

These requirements can be met with the following set-up: An aerial fertilizer coordinator, responsible for all operational logistics, the work program and coordination with estate management, the control of fertilizer preparation and application, the control of operational security, as well as progress reporting to estate and agronomy services; one senior engineer for aircraft maintenance and spare part inventory management; one experienced pilot per aircraft; loader and driver teams (one per aircraft). With a one tonne (t) loading capacity, an experienced pilot can apply up to 70 or 150 t per day, depending on the rate of application.

The cost of aerial application is two to five times greater than manual application, depending on currency value, local cost, and management. This additional cost of application must be balanced by an increase in fertilizer efficiency due to a reduction in nutrient losses, without any adverse impact on yield, as observed by Loong et al. (1990).

Further, the cost of application and the aircraft output is related to application rate (**Figure 3**). High application rates applied in one-run over the working area results in a **relatively** lower cost. However, when the number of runs increases (from two to four for example) due to small application rates or small block sizes, the cost increases significantly.

Figure 3. Cost of fertilizer application and amount applied.



A compromise between the need to apply site-specific fertilizer recommendations (reducing the productivity of the aircraft) and the need to increase the aircraft's performance (by decreasing to an acceptable level of site-specificity of recommendations) is inevitable. In the near future, technological developments will improve the scope for aerial fertilizer application. Electronic flow meters are available for use with solid fertilizers and GPS companies are expected to integrate DGPS and GIS so that actual fertilizer recommendation maps can be uploaded to the aircraft's computer. These developments will make aerial fertilizer an attractive tool for precision plantation agriculture in the next few years. **BCI**

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Nitrogen and Potassium...Important for Oat Hay Yield and Quality

By Stephen Loss

Production of oats for hay and grain is increasing in Western Australia, particularly for the export hay market. Initially, some growers suspected that high rates of fertilizer could have a negative impact on hay quality. However, this study found that adequate nitrogen (N) and potassium (K) fertilization enhanced the yield and quality of oat hay and grain. Nitrogen increased hay and grain yield, and hay protein content. While it appeared that K was less important than N for hay yield, K improved hay quality parameters important for the export market. There was no evidence that high rates of N or K decreased hay quality.

Over 500,000 tonnes (t) of cereals are cut for hay annually in Western Australia from more than 100,000 hectares (ha). Around 150,000 t of oat hay is currently exported, primarily to Japan, with the industry growing rapidly. Exporters have specific quality standards for oat hay to meet market requirements. Limited farmer experience had suggested that high rates of fertilizer might reduce quality. In response, several field experiments were conducted to examine the effect of K and N application on hay yield and quality.

One trial was conducted in 2000 at Yerecoin, and three trials were conducted in 2001 at Yerecoin, Aldersyde, and Williams, which represent the main oat producing regions of Western Australia. All sites were on grey brown, sandy loam soils. Soil fertility characteristics are outlined in **Table 1** for pH, organic carbon (C), nitrate-N (NO_3^--N), ammonium-N (NH_4^+-N), and available P, K, and sulfur (S).

Treatments were a complete factorial of four N rates (0, 30, 60, 90 kg N/ha, except at Yerecoin in 2001 where they were 0, 40, 80, 120 kg N/ha) and three rates of K (0, 30, 60 kg K_2O/ha at Aldersyde and Williams and 0, 48, 96 kg K_2O/ha at Yerecoin). Nitrogen sources were urea in 2000 and liquid urea ammonium nitrate (UAN) in 2001, broadcast on the surface before sowing except for the highest rate, which was split between sowing and four to eight weeks after sowing. Potassium was top-dressed as muriate of potash (KCl) before sowing. At Yerecoin, a soil

Table 1. Soil characteristics (0 to 10 cm depth) at experimental sites, Western Australia.

	Yerecoin	Aldersyde	Williams
Soil pH, calcium chloride	4.5	4.3	5.2
Organic C, %	1.03	0.73	2.75
NO_3^--N, mg/kg	13	8	6
NH_4^+-N, mg/kg	10	5	9
Available P, mg/kg	18	28	58
Available K, mg/kg	24	70	60
Available S, mg/kg	6	7	15

Table 2. Effect of N application on biomass production at spring oat hay harvest, Western Australia.

N rate, kg/ha	Yerecoin (2000)	Williams (2001)	Aldersyde (2001)	Yerecoin deep-ripped area (2001)
0	1.96	5.32	3.44	6.27
30	3.18	6.01	4.60	–
40	–	–	–	7.71
60	3.56	6.41	5.82	–
80	–	–	–	8.97
90	4.21	6.73	5.67	–
120	–	–	–	9.24
LSD (p=.05)	0.64	0.49	0.99	1.83

Table 3. Improvement in crude protein content (%) of oat hay with N application, Western Australia.

N rate, kg/ha	Yerecoin (2000)	Williams (2001)	Aldersyde (2001)	Yerecoin deep-ripped area (2001)
0	7.25	4.68	5.77	6.37
30	7.16	5.01	6.31	–
40	–	–	–	7.44
60	7.71	5.93	6.93	–
80	–	–	–	8.14
90	8.03	5.94	6.97	–
120	–	–	–	9.01
LSD (p=.05)	0.74	0.46	0.58	0.91

compaction layer was noted at about 15 cm depth, and in 2001 half the trial was deep-ripped to 30 to 40 cm three days after sowing. Spring hay production was measured in four quadrats cut from each plot, oven-dried, and analyzed for quality parameters [i.e., protein content, metabolizable energy (ME), digestible dry matter (DDM), neutral detergent fibre (NDF), and acid detergent fibre (ADF)].

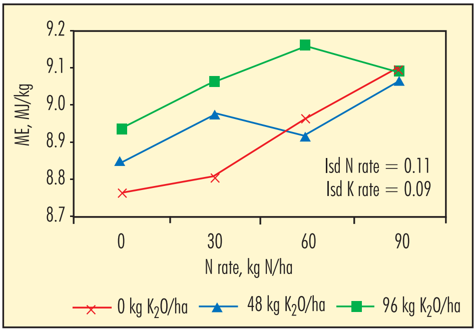
Production and Quality Responses

Application of N increased hay production at all sites (**Table 2**), but there were no significant yield responses to K. Maximum response to N occurred at 40 to 60 kg N/ha at all sites except for Yerecoin in 2000, where increases in biomass did not plateau before 90 kg N/ha. Deep ripping at Yerecoin in 2001 increased average hay production from 6.2 to 8.4 t/ha and there was no response to N or K unless the soil was deep-ripped.

Crude protein content of hay was significantly increased by N application at all sites (**Table 3**). Ripping at Yerecoin and K application had no consistent effect on protein content.

Other hay quality parameters did not respond to N or K application at Yerecoin or Aldersyde in 2001, but at both sites hay quality achieved export standards. On the other hand, the application of fertilizer at Yerecoin in 2000 and Williams in 2001 significantly improved other hay quality parameters. In one case, export standards were met only when K fertilizer had been applied.

Figure 1. Metabolizable energy (MJ/kg) increased with N and K application at Yerecoin, Western Australia, 2000.



At Yerecoin in 2000, the ME of hay was increased by N and K application, from 8.8 mega joules (MJ)/kg at zero N and K to 9.2 MJ/kg at 60 kg N/ha and 96 kg K_2O/ha (**Figure 1**). Digestible dry matter showed similar trends, increasing from 61.5% at zero N and K to 63.5% at 60 kg N/ha and 96 kg K_2O/ha.

While NDF is a measure of the amount of structural carbohydrate in forage (including both digestible and indigestible components) and is negatively correlated with animal voluntary feed

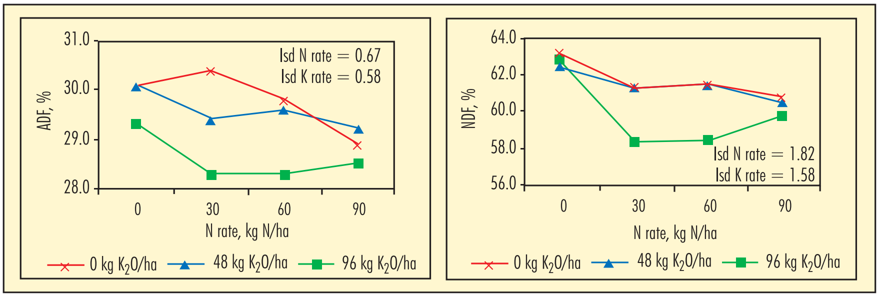


Figure 2. Both ADF (left) and NDF (right) decreased with N and K application at Yerecoin, Western Australia, 2000.

intake, ADF is a measure of indigestible carbohydrates only and is negatively correlated with digestibility. Both NDF and ADF decreased with N and K application (**Figure 2**).

At Williams, quality parameters were not affected by N application, but improved significantly with K application (**Table 4**). Digestible dry matter increased from 60.5% in the control to 62.0% at 60 kg K_2O/ha. Neutral detergent fibre was 58.3% in the control treatment, exceeding the 57% level generally demanded by exporters, but this fell to 56.8% at 30 kg K_2O/ha. Acid detergent fibre fell from 30.7% at zero K to 29.2% at 60 kg K_2O/ha.

Table 4. Improvement in hay quality parameters with K application at Williams, Western Australia, 2001.

K_2O rate, kg/ha	ADF, %	NDF, %	DDM, %	ME, MJ/kg
0	30.7	58.3	60.5	8.65
30	29.7	56.8	61.4	8.80
60	29.2	56.3	62.0	8.86
LSD (p=.05)	1.03	1.53	0.87	0.14

Grain yield was recorded at Yerecoin and Williams in 2001. At Yerecoin, grain yields were significantly greater in the ripped (3.4 t/ha) than the unripped areas (2.9 t/ha). Grain yield also responded to N application reaching a maximum at 80 kg N/ha, but did not respond to the addition of K.

At Williams, grain yields increased with N application from 3.0 t/ha to 3.5 t/ha at 90 kg N/ha. The addition of 30 kg K_2O/ha increased grain yields further, especially at low N rates (**Figure 3**).

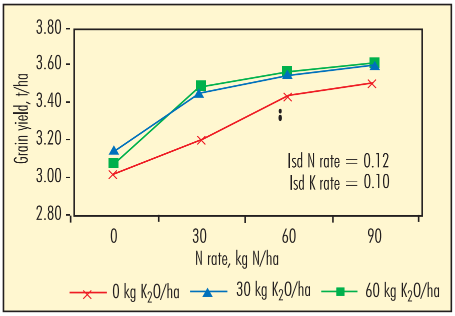


Figure 3. Grain yield was increased with N and K application at Williams, Western Australia, 2001.

Conclusions

Application of N fertilizer improved the hay and grain yield of oats. Apart from hay protein content, N affected hay quality parameters at only one site. On the other hand, K application did not affect the yield of hay, but was able to improve hay quality and could also affect grain yield. There was no evidence that high rates of N or K decrease hay quality. Soil hard pans can restrict oat growth and, hence, limit responses to fertilizer application. **BCI**

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

By S. Abdulrachman, H.C. Gines, R. Nagarajan, S. Satawathananont, T.T. Son, P.S. Tan, and G.H. Wang

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

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

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

Note: Part 1 and Part 2 of this series of articles on Site-Specific Nutrient Management (SSNM) for rice in Asia appeared in *Better Crops International*, 2002, No. 1.

Reductions in Fertilizer Use

Fertilizer use can be reduced at sites where the difference between nutrient requirement for a targeted yield goal and the indigenous nutrient supply is small. The most overused macronutrient in this study was nitrogen (N), as shown in **Table 1.** With SSNM, fertilizer N rates were

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

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

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

reduced significantly, by 10 to 20% at the experimental sites in China (JI), Vietnam (HA and OM), and Indonesia (SU).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

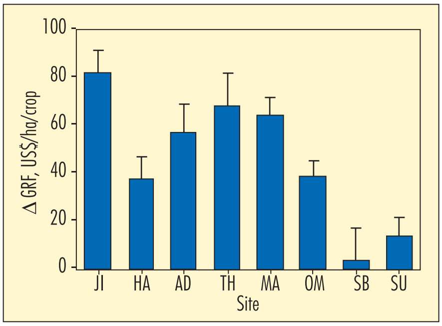
four fertilizer N applications compared to farmer practice where all fertilizer N is applied within the first 10 days after crop establishment). However, the N recovery efficiency was only moderate with SSNM (0.29 kg/kg, **Table 3**), suggesting potential for further improvement in N management.

Increasing Fertilizer Use

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

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

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



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

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

Exploiting the Synergy of Improved Nutrient and Crop Management

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

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

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

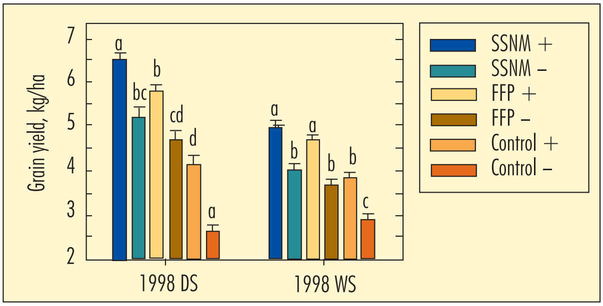


Figure 2. Grain yield (means, standard errors) on 27 farms with SSNM, FFP, and an unfertilized control in Maligaya (MA), Cental Luzon, Philippines, 1998 DS and WS. Farms were grouped according crop management problems (+ little or no problems; – severe problems).*

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

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

Constraints Other Than Nutrient Management

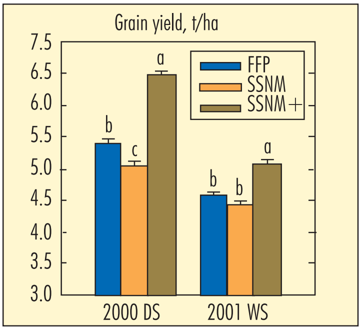
Field observations and the evaluation of N use efficiencies indicated that constraints other than nutrient supply were the major reason for only small yield increases with SSNM at the experimental site in Sukamandi (SU), West Java, Indonesia.

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

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

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

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



Conclusions

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

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Improving Nutrient Management Strategies for Delivery in Irrigated Rice in Asia

By C. Witt, R.J. Buresh, V. Balasubramanian, D. Dawe, and A. Dobermann

An important task is to package the scientific principles of site-specific nutrient management (SSNM) into guidelines for extension workers and farmers.

Fertilizer management in irrigated rice in Asia requires both preventive and corrective nutrient management strategies. Crop response to fertilizer application is not always easy to predict due to the effects of seasonal and year-to-year variation in climate (particularly solar radiation), and spatial and temporal variation of indigenous soil nutrient supplies. Both factors lead to large differences among sites, seasons, and years in optimal rates for fertilizer inputs. Current fertilizer recommendations in Asia, however, typically consist of blanket recommendations with fixed rates and timings for large rice-growing areas.

Considerable progress has been made in recent years in developing field- and season-specific nutrient management approaches, as alternatives to blanket recommendations for nitrogen (N), phosphorus (P), and potassium (K) fertilizers (Balasubramanian et al., 1999; Dobermann et al., 2002). These techniques have been evaluated in a wide range of farmer fields in Asia and are now positioned for wider scale validation and farmer adaptation. This article summarizes current efforts to refine and simplify the underlying principles of SSNM into tools and guidelines for improved nutrient management in Asia's irrigated rice systems.

Note: Part 1 and Part 2 of this series of articles on Site-Specific Nutrient Management (SSNM) for rice in Asia appeared in *Better Crops International*, 2002, No. 1.

Principle 1: Yield gains and fertilizer requirements

The principle described here provides a basic plan for the pre-season calculation of balanced fertilizer rates, based on the difference between the rice plant's nutrient requirements and the soil's nutrient supplying capacity. This deficit depends largely on the expected yield increase, which we define as the difference between the nutrient limited yield and the season-specific yield goal. Yield gains must be estimated separately for N, P, and K to take into account differences in the supply of each nutrient. For example, if the nutrient-limited yield measured in omission plots (see Principle 2) was 5 t/ha for P and 6 t/ha for K, the required yield increase to achieve a yield goal of 6 t/ha would be 1 t/ha for P and 0 t/ha for K. Thus, sufficient fertilizer P must be applied to support the required yield increase, whereas sufficient K must be applied to prevent the long-term depletion of soil K (see Principle 4).

As a rule of thumb, we estimate that 40 kg fertilizer N, 20 kg P_2O_5, or 30 kg K_2O are required to raise the respective nutrient-limited yield by 1 t/ha. These fertilizer rates were calculated based on the approach described by Witt and Dobermann (2002a):

$$FN = (GY-GY_{0N}) \times UN / REN \qquad [\text{equation } 1]$$

$$FP = (GY-GY_{0P}) \times UP / REP \times 2.292 \qquad [-15\%] \qquad [\text{equation } 2]$$

$$FK = (GY-GY_{0K}) \times UK / REK \times 1.2 \qquad [-15\%] \qquad [\text{equation } 3]$$

where FN, FP, and FK are the recommended fertilizer N, P_2O_5, and K_2O rates in kg/ha; GY is the desired yield goal (t/ha); GY_{0N}, GY_{0P} and GY_{0K} are the grain yields measured in nutrient omission plots (0-N, 0-P, 0-K) (t/ha); UN, UP, and UK are the plant uptake requirements of 15 to 20 kg N, 2.6 kg P, and 15 kg K per t grain yield; and REN, REP and REK are the expected fertilizer recovery efficiencies of 40 to 50% for N, 25% for P, and 50% for K. Fertilizer P and K rates were finally reduced by 15% because previous on-farm research has shown that the desired yield goal will not be reached every season due to constraints other than nutrient management (e.g., climate, pests, etc.). Such simple rules are only valid under the following assumption: a yield goal was chosen according to the guidelines outlined by Witt and Dobermann (2002b); moderate to high N efficiencies can be reached with improved nutrient management under field conditions; soil P and K fixation is low to moderate; K losses due to leaching are small; about 4 to 5 t straw/ha is returned after each harvest (incorporated or burned).

Principle 2: Use of omission plots for estimating soil nutrient supplies

Soil nutrient supplies can be estimated indirectly from plant nutrient uptake in omission plots as an alternative to soil testing (Witt and Dobermann, 2002b). Plant-based estimates of soil nutrient supply integrate the supply of all indigenous sources estimated under field conditions and also offer the possibility for estimating the nutrient supplying power of organic manures. For the purpose of extension, soil nutrient supply can be estimated from grain yield in omission plots, assuming an average uptake of 15 kg N, 2.6 kg P, and 15 kg K at harvest per tonne of grain yield/ha (Dobermann and Fairhurst, 2000), or expressed as nutrient-limited yield in the respective omission plot. A major advantage of this approach is that the soil supply is expressed in a unit that can be used directly in the calculation of fertilizer requirements (see Principle 1). Furthermore, soil nutrient supply becomes visible to farmers and thus omission plots are a simple and effective demonstration tool for use by extension workers (see photo).

Installation of nutrient omission plots.

Principle 3: Need-based N management

Asian farmers generally apply fertilizer N in several split applications, but the number of splits, amount of N applied per split, and the time of application vary considerably even within small recommendation domains. Farmer flexibility in adjusting the timing and amount of fertilizer applied offers great potential to synchronize N application with the demand of the rice crop in real-time. In the following, we discuss the three most important N management strategies.

a) **Location-specific N fertilizer splitting schedules for preventive N management** follow a fixed schedule of fertilizer N applications. Such recommendations for location-specific N regimes are in wide spread use, usually developed on-station or on-farm in N fertilizer response experiments. Limitations of fertilizer response experiments include costly and time consuming identification of optimal fertilizer splitting patterns and corresponding fertilizer N rates, and limited potential to extrapolate results due to wide variation in both soil N supply, within large recommendation domains, and crop response due to climatic factors.

Corrective N management strategies offer greater potential for efficient fertilizer N management (see below), but recommendations for location-specific N schedules may be sufficiently accurate under stable climatic conditions with low pest pressure, or where large benefits can be expected from rather crude adjustments in fertilizer N management, such as sites in Zhejiang, China, where fertilizer N use was excessive.

Location-specific split schedules can be developed following Principles 1 and 2 above, where fertilizer N requirements are calculated based on crop requirements and soil indigenous N supply. An estimate of the latter may be obtained by analyzing current farm yields and farmer N management strategies (Dobermann and Fairhurst, 2000) in combination with local knowledge on soil fertility. Thus, N omission plots may not be required to obtain a sufficiently accurate estimate of indigenous N supply. Locally refined N splitting patterns have to take into account specific needs for differences in climatic seasons, varieties, crop establishment, basal N application, and water management (Dobermann and Fairhurst, 2000).

b) **Real time corrective N management** with a leaf color chart (LCC) requires periodic assessment of plant N status, and the application of fertilizer N is delayed until N deficiency symptoms start to appear. This need-based approach to N management does not require the estimation of soil N supply or the calculation of a preseason fertilizer rate. The scientific basis for need-based N management was developed with the introduction of the chlorophyll (SPAD) meter (Peng et al., 1996; Balasubramanian et al., 1999). The costly SPAD meter is not suitable as an on-farm tool, however, and a LCC, modified from prototypes

Leaf color chart.

developed in Japan (Furuya, 1987) and China (by Prof. Tao Qinnan, Zhejiang University) was developed recently through the International Rice Research Institute (IRRI) and the National Agricultural Research and Experimental Systems (NARES) collaboration (IRRI, 1999). Leaf color is a visual and subjective indicator of plant N deficiency, and the LCC, with its six color panels of different shades of green, is used as a reference tool (see photo).

Need-based N management requires the identification of an optimal leaf color that must be maintained throughout the season to obtain high yields. The optimal leaf color (or critical LCC value) varies depending on cultivar and crop establishment method. Guidelines for the use of the LCC include reading of leaf color at seven to 10 day intervals from early tillering until flowering. When the average leaf color of sampled leaves falls below the critical value, a predetermined amount of N fertilizer is applied immediately to correct N deficiency. Standard corrective application rates (less than 40 kg N/ha to ensure efficient fertilizer N use) that take into account yield potential were developed for each season. Large numbers of LCCs have been fabricated and distributed to farmers through collaboration with NARES in several Asian countries. Several versions of LCCs currently exist (IRRI, Japan, China, and University of California Cooperative Extension), and research efforts at IRRI are underway to compare LCCs and explore options for refining and standardizing colors.

c) Location-specific split schedules combined with LCC provide tools for preventive and corrective N management. Total fertilizer N requirements are calculated as described for location-specific split schedules (see above), including guidelines for the need of basal N application. Predetermined N doses are adjusted during later growth stages depending on the plant requirement for fertilizer N. This dual strategy is similar to the SPAD meter approach described by Witt and Dobermann (2002b). Using schedules in addition to the LCC may address some farmer preferences and needs to reduce reliance on frequent visits to the field. Clearly, the most suitable strategy may vary from location to location and will have to be identified through farmer evaluation and validation, and an economic analysis of the strategies tested.

Principle 4: Sustainable crop- and soil-based P and K management

The estimation of P and K requirements is challenging for individual farmers due to small land holdings and substantial variation in the supply of soil P and K within small recommendation domains. Information on soil nutrient supply is particularly important for P and K, because of the difficulty of predicting short- and long-term crop responses to P and K application, and less possibility to correct P and K deficiencies within the cropping period, as compared with N.

In general, nutrient use efficiency is greatest when all P and most K fertilizer is applied early in the season to avoid deficiencies at early growth stages. This requires a conceptual framework to guide farmers in the estimation of season-specific total fertilizer P and K requirements.

Nutrient omission plots placed in representative farmer fields help extension workers to develop an improved understanding of the variability in soil fertility within a recommendation domain in partnership with farmers. The yield gain concept then provides a simple rule for predicting fertilizer requirements (Principle 1). Problems remain, however, with regard to strategies geared towards the long-term maintenance of soil nutrient reserves where a direct crop response to P and K application is not expected.

A simple nutrient balance model was constructed based on the nutrient requirements for targeted yield goals, taking into account the soil nutrient supply estimated from a nutrient omission plot, nutrient inputs from irrigation water, and nutrient removal with grain and straw:

$$FP = GY \times UP - StP + (GY - GY_{0P}) \times UP \times 2.292 \qquad [-15\%] \qquad [\text{equation } 4]$$

$$FK = GY \times UK - StK - WK + (GY - GY_{0K}) \times UK \times 1.2 \qquad [-15\%] \qquad [\text{equation } 5]$$

where StP and StK are the estimated inputs of 0.85 kg P and 13 kg K per t recycled straw, and WK is the average K input with irrigation water during the growing season. See equations 1-3 for further abbreviations. An average input of 25 kg K/ha per crop with irrigation water is assumed here, based on measurements conducted at various sites in Asia, but measurements should be made in each locality. It was further assumed that K input from rainfall equals K losses due to percolation. Fertilizer P and K rates were finally reduced by 15% because of the rules explained under Principle 1. Suggested recommendations for maintenance P and K rates are presented in **Tables 1** and **2**, and minimum P and K rates for yield increases were set to 20 kg P_2O_5 and 30 kg K_2O/ha/t yield (Witt and Dobermann, 2002a).

Rice straw contains relatively little P, so that only a simplified table is presented for cases where only small amounts of straw (2 to 3 t/ha) are returned to the soil (**Table 1**). The fertilizer P requirement largely depends on the deficit between yield goal and soil nutrient supply, and the suggested maintenance fertilizer P rates for conditions where a direct crop response is not expected (yield goal = yield in 0 P plot) increase slightly with an increase in the yield target.

Straw management has a pronounced effect on the maintenance of soil K supply (**Table 2**), because about 80% of the K taken up by the rice plant remains in the straw. Bulk straw incorporation or wide-spread burning has similar positive effects on P and K recycling (Dobermann and Fairhurst, 2000). Where only small amounts of straw are incorporated after harvest (e.g., Bangladesh, India, Nepal, and North

Table 1. Maintenance fertilizer P_2O_5 rates (kg/ha) depending on yield in 0-P plots and yield goal.

Yield in 0-P plots, t/ha	Yield goal, t/ha 4	5	6	7	8
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

* A lower yield goal is recommended when the required yield increase exceeds 3 t/ha.

Vietnam), substantial amounts of fertilizer K would have to be added to balance K removal in straw and grain. Where the amount of straw incorporated is 4 to 5 t/ha, fertilizer K application would only be required if a crop response is expected, and a minimum rate of 30 kg K_2O/ha/t grain yield increase is sufficient (see Principle 1).

The model takes the most relevant input and output parameters into account, and assesses more accurately such important issues as long-term mining and replenishment of soil P and K reserves (Witt and Dobermann, 2002a). Local adaptation and refinement of these generic principles may be required to integrate results of local research (e.g., soil P and K supplying capacity determined in long-term experiments).

Principle 5: Increasing profitability

The major benefit for farmers from improved nutrient management strategies can be expected as an increase in the profitability of rice cropping (Dobermann et al., 2002). The principles of SSNM can accommodate a wide range of socio-economic conditions, including situations of labor shortage. Small amounts of additional labor may be required, but labor costs for nutrient management are relatively small compared to those for land preparation, transplanting or harvesting. Efficient N management may also result in off-farm environmental benefits through a reduction of fertilizer N use without a reduction in yield (Balasubramanian et al., 2000, Wang et al., 2001), especially in situations where N inputs are very large (e.g., China and Java Island in Indonesia). This may increase profitability, particularly in cases of very high fertilizer N inputs (China, Indonesia).

Large reductions in N use in such locations may also increase farm profits, but the cost of fertilizer N is typically less than 7% of the gross revenue from paddy (Dawe, 2001). Thus, a 20% saving in fertilizer N represents less than 2% of gross revenue. The major potential for

Table 2. Maintenance fertilizer K_2O rates (kg/ha) depending on yield in 0-K plots, yield goal, and amount of incorporated straw.

Yield in 0-K plots, t/ha	Yield goal, t/ha: low straw return (0-1 t/ha)					medium straw return (2-3 t/ha)					high straw return (4-5 t/ha)				
	4	5	6	7	8	4	5	6	7	8	4	5	6	7	8
3	45	75	105	*	*	30	60	90	*	*	30	60	90	*	*
4	30	60	90	120	*	0	35	65	95	*	0	30	60	90	*
5	0	45	75	105	135	0	20	50	80	110	0	0	30	60	90
6	0	0	60	90	120	0	0	35	65	95	0	0	10	35	70
7	0	0	0	75	105	0	0	0	50	80	0	0	0	25	55
8	0	0	0	0	90	0	0	0	0	65	0	0	0	0	40

* A lower yield goal is recommended when the required yield increase exceeds 3 t/ha.

increasing farm profitability through innovative nutrient management lies in increasing yield through efficient N management and balanced nutrition. To select the most profitable strategies, farmer participatory evaluation of innovative nutrient management should be accompanied by an evaluation of fertilizer costs comparing combined and straight fertilizers and a gross margin analysis.

Summary

The principles of SSNM were developed through on-farm evaluation in partnership with National Agricultural Research and Extention Systems (NARES) in the workgroup Reaching Toward Optimum Productivity (RTOP) of the Irrigated Rice Research Consortium (IRRC) and the Crop and Resource Management Network (CREMNET). The strategies outlined here can be adapted for use across a wide range of cropping conditions in rice-based systems, including those where large amounts of organic nutrient sources are used.

IRRI is involved in wider-scale farmer evaluation and adaptation of SSNM through partnership with NARES, as part of the IRRC, and through the rice-wheat consortium (RWC). Interdisciplinary NARES teams are involved in on-farm evaluation of innovative nutrient management strategies in Bangladesh, China, India, Indonesia, Nepal, Pakistan, the Philippines, Thailand, and Vietnam. Involvement of public and private sector partners is being strengthened to facilitate dissemination of information and delivery of SSNM to rice farmers. **BCI**

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Dr. Ernst Mutert Retires, Dr. T.H. Fairhurst Named Director of PPI/PPIC East and Southeast Asia Program (ESEAP)

Dr. Ernst Mutert, who served as Director, PPI/PPIC-ESEAP, based in Singapore for 11 years, has retired and returned with his family to live in Germany. Dr. Thomas H. Fairhurst, who served as Deputy Director of the program since 1996, succeeds Dr. Mutert as Director.

A native of Osnabrück, Germany, Dr. Mutert received his D.I.A. and Ph.D. degrees at the University of Kiel and worked as a researcher and lecturer there. He was involved with a soil survey project in Germany and Libya from 1972 to 1981, then joined the staff of Büntehof Agricultural Research Station, Department of Tropical and Subtropical Crops. As a soil scientist, he worked in advisory responsibilities with projects in Africa, South America, and Asia.

In 1991, Dr. Mutert became Director of PPI/PPIC-ESEAP. Numerous accomplishments and advances in the region are credited to his skillful direction.

Dr. Fairhurst was born in England, UK, and earned his Ph.D. at the University of London, Wye College. He has extensive background and experience as an advisor and leader in tropical agriculture. Over the past five years, PPI/PPIC-ESEAP has placed major emphasis on nutrient management in oil palm and rice. Sustainable crop management in both these crops requires attention to the recycling of crop residues and adequate mineral fertilizer use to ensure maximum yield in the short term and to avoid the depletion of soil nutrient reserves in the longer term. **BCI**

Dr. Mutert

Dr. Fairhurst

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Hunger Can't Wait

"The subject of man, his need for food, and what can be done to obtain it is virtually without beginning and certainly without ending."—-Joseph Sander, in *Hunger Can't Wait*. 1975.

I call it 'gaining perspective.' Sometimes it is created by what goes on around us; other times, we get it by stepping back—taking a historical approach. I did that recently when I re-read this book. Another perspective, communicated at the recent World Congress of Soil Science, in Thailand, is: *Soils are not a media simply to study, but to use the resource to meet human needs—food and fibre, and how we do it influences the environment we live in.* Taken together, I hope you find this provides a working perspective for us. My experience is that most of you live this perspective and philosophy.

I like to use this space to congratulate and motivate the readership concerning individual contributions—contributions which improve agricultural productivity, farmer economics, and environmental security. So, at times and like you, I test myself concerning how well I'm doing—we're doing—in making a difference…to better the lives of people. I think we are. I hope you agree.

Now, the tough questions: What are we doing differently, better, or worse than people in our positions did more than 25 years ago when the issue of *hunger can't wait* was addressed?

My observation: We still have good and dedicated researchers—some studying the basic mechanisms and others applying it; we still have progressive farmers adopting better practices; we still have too much out-dated agricultural policy; and, we still have people against change. A working philosophy of mine is that regardless of the negatives, there are still sufficient people to harness together so each individual's contribution results in positive, real, and sustainable development. There are many examples around the world. We need to replicate them, so I ask for your support in reaching out to others—in science and education, industry, policy-making, and farming—to strengthen the coalition for positive change in agriculture. The hungry are agriculture's market opportunity. **The fact is, our perspective on how we work will decide if *hunger can't wait.***

Dr. Mark D. Stauffer
Senior Vice President,
International Programs, PPI
and President, PPIC

Better Crops International,
published by the
Potash & Phosphate Institute/
Potash & Phosphate Institute of Canada

Printed on recyclable
paper with soy ink.