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Phosphorus Fertilization of Soybeans in Clay Soils of Entre Ríos Province

By Pedro Barbagelata, Ricardo Melchiori, and Osvaldo Paparotti

Soil texture plays an important role in determining phosphorus (P) availability. This study examined the clay soils of Entre Ríos and determined a specific critical soil test P level for this region.

Entre Ríos Province in Argentina has a total area of 7 million hectares (M ha) and at present 1.3 M ha are cropped annually. Agricultural production is expected to expand to cover over 4 M ha of the province's potentially arable soils, and the majority will likely be under soybean. In 2000/01, the soybean area was 580,000 ha and grain production was greater than 1.65 million tonnes (M t). This represents a 113 percent increase in cropped area compared to the previous five-year average. Recent changes in agricultural practices, such as no-tillage and glyphosate herbicide-resistant soybean genotypes has simplified crop management, and is a partial explanation for this significant increase.

The dominant soils in the agroecological zone experiencing the fastest agricultural expansion are Vertisols. These soils are characteristically found on long slopes (0.5 to 2.5 percent); they are dark in color, high in clay content, and have a strong tendency to shrink and swell as soil moisture changes. Soil texture is commonly silty-clay-loam in the topsoil horizons…some soils may have up to 45 percent clay…and silty-clay or clay in the subsurface horizons, which are very dense with very little permeability. If not eroded, these soils have relatively high organic matter contents (3.5 to 6 percent). However, they often produce crop symptoms of nitrogen (N) and P deficiency.

Sustainable agriculture relies on maintenance of adequate soil fertility and replenishment of nutrients removed by harvested grain. Phosphorus replenishment is particularly important in these clay soils that have very low native P availability levels (Darwich, 1980; Tasi, 2000). Soil testing is the most precise available tool to: 1) determine whether P deficiencies are the cause of low soybean yields, and 2) prescribe adequate P fertilization rates (Melgar et al., 1995). However, some reports suggest results can be erratic

Visitors are shown during field day at the Paraná experiment site.

Table 1. Phosphorus availability, pH, organic matter (OM), total N content, and preceding crop at eight study sites (Entre Ríos Province).

Sites	Bray P-1, ppm	pH	OM, %	Total N, %	Preceding crop
Las Tunas	6.2	7.8	4.14	0.188	Sorghum
Viale	9.8	7.5	4.37	0.195	Corn
Tala	7.1	7.4	3.39	0.178	Soybean
M. Grande	7.2	7.0	4.69	0.223	Soybean
Paraná	9.5	7.1	3.28	0.150	Corn
Villaguay	7.6	6.4	4.25	0.213	Corn
Uruguay	8.0	7.6	4.10	0.186	Wheat
La Paz	14.7	7.5	5.20	0.245	Rice

(Gutiérrez Boem et al., 1998).

There is a need to continue research on adjusting and validating soil P testing and P fertilization practices for improved productivity in the region. This study evaluated P fertilization effects on soybean yield and determined a critical P level for clay soils in Entre Ríos.

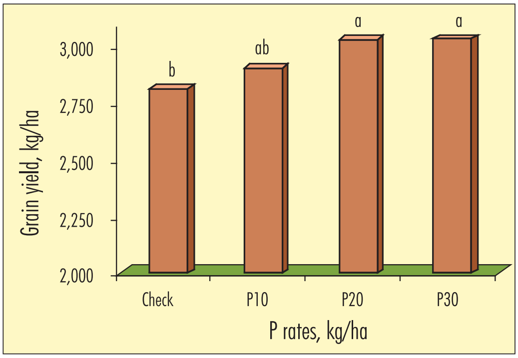
Material and Methods

Eight on-farm experiments were carried out on Argilic Pelluderts soils during 1999/00 and 2000/01 in Paraná, La Paz, Villaguay, and Concepción del Uruguay in Entre Ríos Province. Six sites were under no-tillage and two under conventional tillage. Soybean cultivars of maturity groups IV to VII were planted from November 8 to December 23 with row spacing from 0.38 m to 0.52 m. Experimental design was a randomized complete block with three or four replications. Four treatments included a control, and rates of 10 (P10), 20 (P20), and 30 (P30) kg P/ha. Phosphorus was applied at planting and was banded below the seed as triple superphosphate (0-46-0). At maturity, 15 m^2 were hand harvested to determine grain yield. Results were analyzed by ANOVA using procedures of the Statistical Analysis System (SAS, 1999). The critical P level was determined by Cate and Nelson graphic methods (Cate and Nelson, 1965). Relative yield (RY) was determined by dividing the yield observed in the control by the average yield of the most productive treatment. Initial soil conditions of all experimental sites are shown in **Table 1**.

Results and Discussion

Average soybean yield was 2,940 kg/ha and varied from 1,800 to 4,290 kg/ha. Phosphorus fertilization significantly affected soybean grain yield in all sites, but no differences were determined between P10, P20, and P30, and between P10 and the control (**Figure 1**). Average yield responses to P varied from 87 kg/ha (P10) to 217 kg/ha (P30).

Figure 1. Average soybean grain yield as function of P rates. Different letters indicate statistically significant differences among treatments according to LSD test ($p < 0.05$).



A critical level of 9.5 parts per million (ppm) was determined from the relationship between P availability (Bray P-1) and RY using the Cate and Nelson graphical method (**Figure 2**). Only four observations were considered outliers (i.e., data points located in the upper left and lower right quadrants) (14 percent error). Applying this critical soil P level, the average yield response to P fertilization in soils testing within the deficiency range was 249 kg/ha, whereas above this critical level no response was found.

Melgar et al. (1995) reported a similar critical level in a study of 65 experiments in Buenos Aires and Santa Fe Provinces. Other results suggest a higher critical level (Gambaudo and Fontanetto, 1996; Mallarino, 1999; Berardo, 2000). Soils of these previous experiments were silty or silt loam, and as suggested by Cox (1994), the silty-clay-loam texture of this study's Vertisolic topsoils can explain the difference.

Results of these on-farm experiments validate soil P testing as an adequate diagnostic tool to improve soybean P fertilization management in clay soils of Entre Ríos Province. A high probability of soybean yield response to P fertilization is expected when soil P is below 9.5 ppm. **BCI**

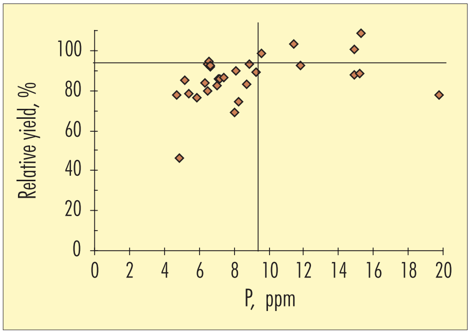


Figure 2. Soil P (Bray 1) critical level for soybean crops in clay-textured soils of Entre Ríos province.

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Yield and Quality of Fruits of Solanaceous Crops as Affected by Potassium Fertilization

By Ni Wuzhong

Potassium (K) fertilization of eggplant, tomato, sweet pepper, and chili produced higher yields and better quality fruit in Zhejiang province of China.

Solanaceous crops such as eggplant, tomato, sweet pepper, and chili are important fruits grown intensively in summer and autumn in the vegetable gardens of south China. They have a high K demand and the harvested fruit removes a large amount of K from the soil.

Generally, input of K fertilizer to these crops is much less than amounts removed. Furthermore, organic manure use, previously the main K sources, has diminished over the last decade, intensifying the depletion of available soil K in most garden soils. As a result, crop yield and quality have fallen (Jiang Xianming, 1990; Zhan Changgeng, 1991).

Consumption of solanaceous crops has increased along with urban, non-agricultural population expansion in China. For consumers, produce quality is a major concern needing consideration in research. This paper documents a series of field experiments where the effects of K fertilization on fruit yield and quality of eggplant, tomato, sweet pepper, and chili were investigated with the purpose of satisfying demand and identifying a rational K fertilization program.

Field experiments were carried out on two silty loam soils with eggplant, tomato, sweet pepper, and chili. Soil test results are given in **Table 1**. Potassium treatments were 0 (K_0), 112.5 (K_1), 225 (K_2), and 450 (K_3) kg K_2O/ha for eggplant, tomato, and sweet pepper, while chili received 0, 67.5, 135, and 270 kg K_2O/ha. Except for the check (Ck) treatment (no fertilizer) the doses of nitrogen (N) as urea and P as single superphosphate were constant for eggplant, tomato, and sweet pepper,

Table 1. Soil test results for two field sites growing solanaceous crops, Zhejiang, China.

Crop	pH H_2O	Organic matter	Total N	Total P	Total K	Hydrolizable N	Available P	Exchangeable K
			mg/kg					
Eggplant	6.5	11.4	0.94	0.56	16.4	134	57	47
Tomato	6.7	11.6	1.21	0.57	15.4	107	40	42
Sweet pepper	Same as tomato experiment							
Chili	Same as tomato experiment							

Table 2. Fruit yields (t/ha) and coefficient of variation (CV) of K treatments on four test crops, Zhejiang, China.

Treatment	Eggplant yield, t/ha	CV, %	Tomato yield, t/ha	CV, %	Sweet pepper yield, t/ha	CV, %	Chili yield, t/ha	CV, %
Ck	3.6 e D**	12.4	-	-	-	-	-	-
K_0	9.9 d C	11.0	27.2 D	5.7	16.8 D	8.9	7.8 D	17.1
K_1	10.6 d C	6.0	33.0 C	4.6	27.0 C	5.6	16.6 C	9.7
K_2	13.7 c B	2.2	38.1 B	4.2	33.1 B	5.7	24.0 B	5.5
K_3	16.8 a A	2.9	44.8 A	3.9	39.2 A	3.7	29.5 A	5.5
K_3*	14.8 b B	6.9	-	-	-	-	-	-

*Muriate of potash used as the source of K.
**Means followed with a different letter are significantly different at $p<0.01$ (a, b, c, d, e) or 0.05 (A, B, C, D) level in Duncan's test.

at 345 kg N and 105 kg P_2O_5/ha, while chili received 207 kg N and 63 kg P_2O_5/ha. Potassium was applied as potassium sulfate (K_2SO_4) for all treatments. In the eggplant trial there was an additional treatment of 450 kg K_2O/ha as potassium chloride (KCl). A randomized complete block design was used for eggplant and a latin square design for tomato, sweet pepper, and chili. All trials had four treatment replications. Important crop quality characteristics determined were dry matter (calculated from the weight difference before and after oven drying at 80°C), sugar content, and vitamin C content.

Potassium fertilization significantly increased fruit yield of eggplant, tomato, sweet pepper, and chili. There was no yield difference between treatment K_1 and treatment K_0 (zero K) in the eggplant experiment (**Table 2**). Potassium application also stabilized yield as the CV of fruit yield diminished with higher rates of K. Comparing treatment K_0 (no K fertilizer) with treatment K_3 (450 kg K_2O/ha), the yield increases obtained were: eggplant, 6.9 t/ha; tomato, 17.6 t/ha; and sweet pepper, 22.4 t/ha. For chili, the difference between treatment K_0 and treatment K_3 (270 kg K_2O/ha) was 21.7 t/ha.

Fruit dry matter content significantly increased with higher rates of K (**Table 3**). However, fruit dry matter content of tomato and sweet pepper decreased at the highest K level (450 kg K_2O/ha). This is likely related to increased water absorption by plants supplied with high K fertility (Mengel and Kirkby, 1987). Fruit vitamin C contents of tomato, sweet pepper, and chili exhibited similar increases with higher rates of K fertilization. Potassium rates above 225 kg K_2O/ha tended to lower dry matter and vitamin C content of tomato and sweet

Table 3. Dry matter and vitamin C contents of fruits of solanaceous crops as affected by various rates of K fertilizers, Zhejiang, China.

	- - - - - - - Dry matter content, % - - - - - - -				Vitamin C content, mg/100g fresh weight		
Treatment	Eggplant	Tomato	Sweet pepper	Chili	Tomato	Sweet pepper	Chili
Ck	7.02 b c**	-	-	-	-	-	-
K_0	6.50 c	5.82 b	6.02 b	10.6 c	22.8 b	126 b	195 c
K_1	7.25 a b	6.67 a	6.89 a	12.8 b	26.1 a	158 a	222 b
K_2	7.79 a	7.15 a	7.47 a	14.1 a b	28.3 a	173 a	239 a b
K_3	7.86 a	6.94 a	7.22 a	14.5 a	27.8 a	164 a	251 a
K_3*	7.33 a b	-	-	-	-	-	-

*Muriate of potash used as the source of K
**Means followed with a different letter are significantly different at $p<0.05$ level in Duncan's test.

Table 4. Effects of K fertilization on sugar content, titratable acidity, and S:A ratio of tomato, Zhejiang, China.

Treatment	Sugar content, %	Titratable acidity, %	S:A ratio
K_0	3.45 c*	0.46 c	7.50 a
K_1	3.67 b c	0.58 b	6.33 b
K_2	3.84 a b	0.66 a b	5.82 b
K_3	4.09 a	0.72 a	5.68 b

*Means followed with a different letter are significantly different at $p<0.05$ level in Duncan's test.

pepper. In addition, K application increased sugar content and titratable acidity levels of tomato and decreased the ratio of sugar content to titratable acidity (S:A) as shown in **Table 4**. A lower S:A ratio translates into better tasting tomato fruit. These results confirm previous reports.

At the high rate of K fertilization (450 kg K_2O/ha), K_2SO_4 was found more effective than KCl on eggplant fruit yield, yield stability (**Table 2**), and eggplant fruit quality (**Table 3**). This agrees with Vlasyuk and Klimovitskaya (1955), who found K_2SO_4 increased dry matter, sugar, and vitamin C contents, and the proportion of marketable fruit. Few studies have examined the effect of K source on eggplant.

Potassium not only increased fruit yields of solanaceous crops, but also improved fruit quality by increasing dry matter and vitamin C contents, as well as increasing sugar content and titratable acidity levels of tomato to reduce the S:A ratio. Potassium sulfate was found more effective on eggplant yield and quality at high rates of K. The additional yield and quality attributable to K_2SO_4 gives farmers sufficient profit to cover the additional cost of this K fertilizer source. Eggplant growers under high K fertilization regimes, using the same soil conditions as this trial in Zhejiang, should apply K_2SO_4 for maximum yield and quality. **BCI**

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Potassium Requirements for Garlic under Fertigation

By J.Z. Castellanos, J.L. Ojodeagua, F. Méndez, G. Alcantar, S. Villalobos-Reyes, P. Vargas, J.J. Muñoz-Ramos, and I. Lazcano-Ferrat

The practice of fertigation is expanding yield potential by reducing plant growth limiting factors. This research provides a better estimate of the nutrient demands of garlic under fertigation, which is necessary to obtain optimal production levels.

Crop yields under fertigation have shot up to potentials never before imagined (Papadopoulos, 1987; Hartz, 1994; Castellanos et al., 2001a). The principal reason for this increase is an optimized delivery system for water and nutrients which eliminates most plant growth limiting conditions. At high yield levels, nutrient demand also increases well above levels considered normal for furrow irrigation systems (Castellanos et al., 2001b). In light of the higher nutrient demand, it is important to review the rates of fertilization supplied to crops under modern fertigation sytems.

Potassium (K) is a very important nutrient for increasing garlic yields. Proper application rates and timing are critcal for generating a yield or quality response. As crop yields increase, the amount of K required also increases, along with all other nutrients. The amount applied ranges from 60 to 150 kg K_2O/ha, depending on the soil K level, crop yield goal, and the site's soil characteristics.

Three basic steps are involved in maximizing garlic yield under fertigation: 1) soil analysis to prepare the most suitable fertigation program, 2) knowledge of the crop's nutrient demands throughout the season, and 3) reliable reference indices for nutrient concentrations in the most recently matured leaf (MRML), in order to correctly interpret tissue analyses and to fine-tune the fertigation program. A limited amount of literature has been published on these last two factors.

Garlic's demand for K ranges from 125 to 180 kg K_2O/ha (Bertoni and Morard du L. Espagnacq, 1988; Zink, 1963). However, only one report has been published on tissue analysis for diagnosis of K status in this crop, and this reference only covers limited stages of crop development (Tyler et al., 1988). This source indicates that the correct content of K in the MRML varies from 4 percent in the pre-bulbing stage, to 3 percent in the bulbing stage and 2 percent in the post-bulbing stage. The MRML can be identified for sampling by the characteristic "ring" at its base, circling the stem. Garlic is a long-season crop that remains in the field for up to seven months, reference information on leaf K status from the beginning of the season to the end is required. This would give farmers the opportunity to accurately identify and promptly correct any deficiencies.

The study was conducted in a Vertisol with a pH of 7.8 (soil:water of 1.2), 2.1 percent organic matter, 14 parts per million (ppm) Olsen-P, 18.1 cmol_c calcium (Ca)/kg of soil, 5 cmol_c magnesium (Mg)/kg of soil, 2.8 cmol_c K/kg of soil, 5.7 ppm of DTPA-iron (Fe), 0.8 ppm of DTPA-copper (Cu), 1.2 ppm of DTPA-zinc (Zn), and 12 ppm of DTPA manganese (Mn). The research was conducted at the Celaya Agricultural Research Station of the National Institute of Agricultural Research (INIFAP), located in central Mexico at 20° 15' north latitude, 101° 39' west longitude, and at 1,650 meters above sea level, with a mean annual temperature of 19°C.

The study consisted of two experiments, one conducted in 1997-98 using furrow irrigation, and a second in 1998-99 in which fertigation was used. Plant K uptake data and the resulting uptake curves were obtained for both experiments, while the third fertigation experiment, (established in 1999-00) explored the effects of plant density on yields and the amount of K taken up by garlic plants.

In all three experiments, the crops received 80 kg of P_2O_5/ha at the time of planting and 240 and 285 kg of N/ha during the 1996-97 and 1997-98 growing seasons, respectively. In the plant density experiment, 405 kg N/ha was applied in 1999-00. In the 1997-98 experiments, N was divided into three applications throughout the season, while in the fertigation experiments N fertilizer was applied with irrigation water according to crop demand. In all three experiments, K was applied at 100 kg K_2O/ha. In the 1997-98 furrow irrigation experiment, plant density was 300,000 plants/ha, while in the 1998-99 fertigation experiment it was 380,000 plants/ha. In the 1999-00 experiment, four different plant density treatments (300,000, 400,000, 500,000, and 600,000 plants/ha) were evaluated for yield and quality factors. In all cases, the cultivar was ***cv.*** Tacascuaro.

Figure 1. Potassium extraction by garlic under different production levels in a Vertisol in central Mexico.

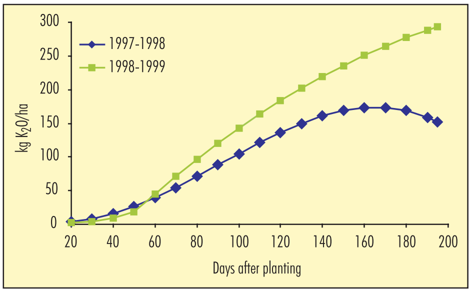

Figure 1 shows the amount of K taken up by the crop during the entire season in both experiments. Garlic demanded very little K in the first 50 days after planting, but increased substantially after that date. In the furrow irrigation experiment, K_2O uptake by the crop was 175 kg K_2O/ha, while in the fertigation experiment it was 295 kg K_2O/ha. Crop yields were 19.1 t/ha in the 1997-98 furrow irrigated crop and 29 t/ha in the 1998-99 fertigation experiment. The higher yield potential of the fertigated crop increased plant demand

for K by almost 70 percent. Based on these results, it was concluded that for every tonne of garlic produced, as much as 9.1 to 10.1 kg of K_2O is taken up by the crop.

The effects of plant density on crop yield are shown in **Figure 2**. Garlic is highly responsive to plant density. Yields increased from 31 t/ha at 300,000 plants/ha to 39.7 t/ha at 600,000 plants/ha, with K uptake increasing from 238 to 302 kg K_2O/ha.

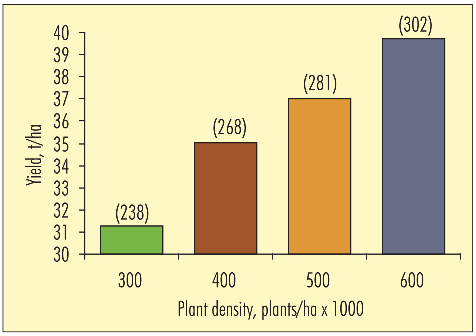

Figure 2. Bulb yield and K extraction (kg K_2O extracted per ha) of garlic under fertigation for four different population densities, central Mexico.

As garlic yields increased, bulb size decreased. This affects the value of the crop in the fresh market. For industrial purposes, high population density is not a problem; otherwise it may be more convenient to use a plant density of 300,000 plants/ha.

Two experiments indicate that through the greater part of the developmental stage the concentration of K in the MRML for optimum yield is between 2.5 to 3.5 percent, although this value decreased in furrow irrigation and was higher with fertigation.

As crop yield potential goes up, the amount of K needed by the crop also increases. No similar outstanding yields have been reported in the literature, and we believe that these results are due to the use of well-adapted cultivars and the effective use of fertigation. **BCI**

Dr. Castellanos, Dr. Ojodeagua, Dr. Méndez, Dr. Villalobos-Reyes, Dr. Vargas, and Dr. Muñoz-Ramos are with the National Institute of Agricultural Research (INIFAP), Mexico. Dr. Alcantar is with Colegio de Postgraduados, Montecillos, Mexico. Dr. Lazcano-Ferrat is Director, PPI/PPIC Mexico and Northern Central America Program (INPOFOS), Queretaro, Qro, Mexico; e-mail: lazcano@ppi.far.org.

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Optimal Phosphorus Management in Rice-Wheat Systems

By Bijay-Singh, Yadvinder-Singh, C.S. Khind, and R.K. Gupta

The annual rice-wheat system brings together conflicting and complementary practices as repeated transitions from aerobic to anaerobic to aerobic soil conditions result in unique changes in the physical, chemical, biological, and nutritive properties of soil. The rice-wheat rotation is one of the world's largest agricultural production systems, and occupies about 14 million hectares (M ha) of cultivated land in the Indo-Gangetic Plains in India, Pakistan, Bangladesh, and Nepal. Its production provides staple grains for more than one billion people, or about 20 percent of the world's population.

Both rice and wheat are exhaustive feeders, and a rice-wheat double-cropping system can quickly deplete soil of its nutrient content. A rice-wheat sequence that yields 7 t/ha of rice and 4 t/ha of wheat takes up more than 300 kg nitrogen (N), 30 kg phosphorus (P), and 300 kg potassium (K) per hectare from the soil. Even with the current recommended rate of fertilization for this system, a negative balance of the primary nutrients exists. The system commonly shows signs of fatigue and is no longer exhibiting increased production with higher input use.

This article addresses how farmers can manage P in their rice–wheat rotations in order to maintain yields, while sustaining – or improving – soil P status. Key questions addressed are: 1) How much P fertilizer should be applied in one rotation cycle? and 2) How much P should be applied to the wheat and rice phases of this rotation?

The amount of P to apply on wheat and rice depends on crop P demand, potentially available soil P resources, and the chemical processes that cause fluctuations in soil P supply under aerobic and anaerobic conditions. On a Typic Ustochrept (10 kg Olsen P/ha) at Ludhiana, India, seven P fertilizer treatments applied to rice and wheat (**Table 1**) were compared from 1990 to 1999.

Phosphorus accumulation and wheat yield in rice-wheat P treatments receiving 60 or 90 kg P_2O_5/ha to wheat (i.e., [1] $P_{0\text{-}60}$, $P_{0\text{-}90}$, $P_{30\text{-}60}$, and $P_{60\text{-}60}$) were significantly greater than in those receiving less than 60 kg P_2O_5/ha, or rice-applied P treatments (i.e., $P_{0\text{-}0}$, $P_{60\text{-}0}$, and $P_{30\text{-}30}$). Phosphorus application to rice increased P accumulation by rice, but did not consistently increase rice yields because flooding can decrease soil P sorption and increase P diffusion, resulting in higher P supply to rice. Applying only 60 kg P_2O_5/ha to wheat and no P to rice led to a

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[1] Treatment abbreviations denote P_2O_5 rate applied to wheat followed by P_2O_5 rate applied to rice.

Table 1. Grain yields of rice and wheat (nine-year average) and total P input-output balance for different P management strategies in the field experiment at Ludhiana, India

P applied, kg P_2O_5/ha		Grain yield, t/ha		P accumulation, kg/ha		Total P input-output balance, kg/ha
Rice	Wheat	Rice	Wheat	Rice	Wheat	
0	0	5.03	2.41	16.6	7.5	-271.2
0	60	5.13	4.69	17.1	14.8	-51.2
0	90	5.08	4.82	17.8	15.4	54.8
30	30	5.27	4.21	19.0	12.5	-48.0
30	60	5.15	4.72	18.6	15.4	47.9
60	0	5.38	3.36	20.1	10.5	-39.6
60	60	5.30	4.94	20.0	15.9	148.7

negative P balance and a decline in soil P (**Table 1**). The P balance was positive in treatments in which more than 90 kg P_2O_5/ha/year was applied.

A sustainable P management strategy must ensure high and stable overall food production, high annual profit, and sufficient P supply to achieve potential yield increases. Major agronomic considerations derived from our experiment are described below.

A rice-wheat system with a total P input less than 60 kg P_2O_5/ha/year was inferior with regard to yield, P uptake, overall profit, P input–output balance, and maintenance or improvement of soil fertility. Only treatments with a total P input of 90 to 120 kg P_2O_5/ha/year had a positive P balance and led to maintenance or an increase in soil P levels.

Sustainable management should aim at increasing Olsen P to a level between 12.5 to 25 kg P/ha on soils of the Indo-Gangetic Plains. Discounting the inferior $P_{60\text{-}0}$ treatment (low wheat yield), this range of available P was only achieved with the $P_{30\text{-}60}$ and $P_{60\text{-}60}$ treatments.

Total P input should be close to the amounts removed (output) by high yields occasionally achieved to ensure sufficient supply in favorable years and after other constraints to growth are removed. Attainable yields of 6 t/ha wheat and 7 t/ha rice require a total P supply of about 42 kg P/ha/year (17 kg P/ha for wheat and 25 kg P/ha for rice).

Soil P supply should be emphasized in wheat instead of rice. Any increase in the solution P concentration through P fertilizer application will have greater benefits in wheat. On soils testing 11 kg Olsen P/ha, a significant wheat yield response up to 90 kg P_2O_5/ha has been observed at several locations in northwest India. Band application of P below the seed and use of sufficient irrigation should be standard practice to increase soil P supply to wheat.

Management strategies with no P applied to rice were less sustainable in agronomic terms, even though the yield response to in-crop application was inconsistent due to factors other than P deficiency. Raising rice yields beyond the present level of 5.5 t/ha will require in-crop P application.

Summarizing, the agronomic indicators in our experiment suggest that: 1) the total P input should be in the range of 90 to 120 kg P_2O_5/ha/year, 2) at least 60 kg P_2O_5/ha must be applied to wheat to achieve yields greater than 5 t/ha, and 3) not more than 35 to 55 kg P_2O_5/ha should be applied to rice. **BCI**

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Effect of Different Levels and Sources of Potassium on Growth, Yield, and Quality of Sugarcane

By Tallat Masud Khosa

Sugarcane is an important cash and industrial crop of Pakistan, occupying about 1 million ha with an average yield of about 50 t/ha...much lower than the world average of 60 t/ha. This research shows significantly higher cane yield and quality can be achieved by adequate and balanced fertilization. Results indicate an increase of 30 percent due to the application of potassium (K).

In Pakistan, K fertilizer use is less than 1 kg/ha and is essentially insignificant when compared with the national average of 85 kg of nitrogen (N) and 21 kg of phosphorus (P) per hectare. Because soils in Pakistan are developed from micacious alluvium, they are generally considered to be well supplied with K. However, crops are becoming more responsive to K fertilization with the introduction of high yielding varieties and the continuation of intensive cropping practices.

Potassium deficiency exerts a negative effect on photosynthesis and carbohydrate transport in sugarcane and high rates of K are required for maximum economic cane yield. In order to study the effect of balanced fertilization on the yield and quality of sugarcane, a project was designed to determine both the appropriate rate as well as the economic effect of using different sources of K.

Balanced fertilization including K resulted in higher yield and improved quality of sugarcane in Pakistan research.

The effect of different sources and levels of K on growth, yield, and quality of sugarcane was investigated on sandy clay loam soil under the agroclimatic conditions of Faisalabad, Pakistan. Available soil K at the site was 174 parts per million (ppm). The test crop was ratooned sugarcane cv. Co-1148. Muriate of potash (MOP) and sulfate of potash (SOP) were used as K sources. The experiment used a split plot design with four replicates with sources of K in main plots and four levels of K (i.e., 0, 100, 150, and 200 kg K_2O/ha) in sub plots. Uniform rates of N and P were applied at 200 kg N/ha and 150 kg P_2O_5/ha, respectively.

Effect of Potassium on Sugarcane Growth, Yield, and Quality

Source of K had no effect on growth, yield, or quality of ratoon sugarcane, as both sources were equally effective. However, as described below, K application rate significantly influenced growth, yield, and quality (**Table 1**).

Table 1. Summarized data of sugarcane response to potash, Faisalabad, Pakistan.

K_2O levels, kg/ha	Yield parameters						
	Length, m	Diameter, cm	Inter-nodal length, cm	Stripped cane, kg	CCS, %	Sucrose, %	Yield, t/ha
0	2.21	2.31	10.2	0.90	9.6	14.6	77.2
100	2.34	2.35	10.4	1.12	10.2	15.2	97.5
150	2.40	2.36	10.7	1.20	10.7	15.8	98.2
200	2.49	2.36	10.8	1.23	11.2	16.5	100.8

Number of millable canes per unit area, cane diameter, and length of internodes increased with increasing rates of K fertilizer. Application of 200 kg K_2O/ha produced the longest canes (2.5 m). Maximum weight per stripped cane (1.23 kg) was attained in plots treated with either 150 or 200 kg K_2O/ha and decreased to 1.12 kg for canes harvested from the plots treated with 100 kg K_2O/ha. Maximum stripped cane yield (101 t/ha) was obtained from the plots treated with 200 kg K_2O/ha. Minimum stripped cane yield (77 t/ha) was harvested from the control plots.

Sucrose in the cane juice obtained from control plots was 14.6 percent against the significantly higher sucrose content of 16.5 percent found in plots treated with 200 kg K_2O/ha. Commercial cane sugar (CCS) percentage exhibited the same response trend to increasing K rates as sucrose content. Minimum CCS (9.6 percent) was found in the cane juice from control plots and significantly higher CCS (11.2 percent) was measured in the cane juice obtained from plots supplied with 200 kg K_2O/ha.

Conclusions

Both the sources of K (MOP and SOP) are equally effective in promoting growth, yield, and quality of ratoon sugarcane. Results showed that 100 kg K_2O/ha applied in combination with 200-150 kg N-P_2O_5/ha provided a large improvement in the sugarcane yield and quality parameters compared to the NP treatment. However, given the application rates selected for this study, it can be concluded that higher K application rates provided steady improvements in both yield and quality. The N-P_2O_5-K_2O combination of 200-150-200 produced superior results, but it appears that the yield curve was not broken. The question needs to be asked whether yield and quality benefits can be accrued with higher, or perhaps better timed, fertilizer application rates on these sandy clay loam soils of Faisalabad, Pakistan. **BCI**

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Site-Specific Nutrient Management in the Highlands of Cartago Province

By Floria Bertsch, Carlos Henriquez, Floria Ramírez, and Freddy Sancho

A coffee/sugarcane plantation located in the highlands of Cartago Province in Costa Rica has overcome many obstacles and has successfully adopted the principles of site-specific nutrient management to its unique landscape.

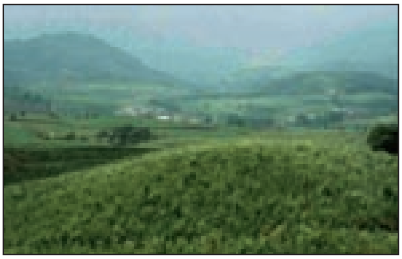
Aerial photograph of San Juan de las Viñas, Costa Rica.

Traditionally, the highlands of Central and South America have been excluded from large-scale implementation of technologies accompanying site-specific nutrient management due to problems of equipment availability and terrain accessibility. However, new ideas on how these challenges can be overcome may allow site-specific management to be adopted on all landscape types.

The main objective of this project's site-specific system was to manage plantation crops according to site characteristics, maximize the use of available inputs and resources, and minimize any detrimental effects the cropping system might have on the environment. Several years of on-farm experience with extensive fields near San Juan de Viñas, Costa Rica, clearly demonstrated that fertility management based on mean nutrient contents has created more problems than it has solved. The first steps toward site-specific management produced interesting results and by 1999 it became obvious that this approach was the best option.

The study was initiated on 250 ha at El Sitio Farm located in the highlands of the province of Cartago, Costa Rica. The site's land relief is very irregular and the farm is occupied by 100 ha of coffee and 150 ha of sugarcane. Coffee is grown on the most irregular side of the farm, while sugarcane areas tend to be located on the flatter terrain (see photos on next page).

Land used for coffee production is divided into 20 fields that differ in size, crop variety, and shade level. Soil test information is available for the last five years and yield records have been kept for three years



Left: Land used in coffee cultivation in El Sitio farm, Viñas, Costa Rica.

Right: Land used in sugarcane cultivation in El Sitio farm, Viñas, Costa Rica.

for each field. The most difficult task has been to obtain reliable yield data due to the manual system used for fruit harvesting.

After much change in sugarcane field size and number, the land under sugarcane is now securely divided into eight fields. This stability is allowing for generation of consistent information from the fields. Soil test information has been gathered for the past five years using a 24 month production cycle. Yield information has been gathered for the last 11 years, but some limitations exist due to the various adjustments in field size in the past.

Both coffee and sugarcane areas have been in continuous cropping for more than 40 years. The effect of this use on the soil characteristics is shown in **Table 1**. Soils are classified as Udands in the Andisol order and it is probable that these soils were more or less uniform when farming began since they are derived from the same parental volcanic ash. However, more than 40 years of cropping has created measurable differences in some soil properties.

Table 1. Average soil tests for the coffee and sugarcane fields, El Sitio farm, Viñas, Costa Rica.

Crop	Year	No. of fields	pH	Acidity saturation, %	ECEC[1]	Total acidity	Ca	Mg	K	P	Mn	Zn
					----------- cmol$_{(+)}$/L -----------					----- mg/L -----		
Coffee	1997	20	4.6	29	11.62	3.1	7.15	0.75	0.62	50	17	3
Sugarcane	1998	8	5.2	17	3.85	0.7	3.85	2.78	0.21	0.2	6	2

[1]ECEC = Effective cation exchange capacity.

Adequate levels of phosphorus (P) and potassium (K) in the coffee fields are the result of uniform and constant application of these nutrients to coffee – historically the most profitable crop. Sugarcane fields are generally lower in P and K since the extraction of nutrients is higher than the amount applied as fertilizer. **Table 2** compares nutrient application in the coffee and sugarcane fields before 1997.

Table 2. Nutrient uptake and application in coffee and sugarcane fields, El Sitio farm, Viñas, Costa Rica.

		Nutrient uptake			
		N	P_2O_5	K_2O	Mg
Crop	Yield	----- kg/ha/year -----			
Coffee	45 fanegas[1]/ha	115	18	140	10
Sugarcane	180 t/ha	87	53	225	22
		Nutrient application			
		N	P_2O_5	K_2O	Mg
Crop	Date	----- kg/ha/year -----			
Coffee	Prior 1997	216	62	108	94
Sugarcane	Prior 1997	97	57	83	26

[1]One fanega = 225 kg of recently harvested fresh mature fruit.

Preliminary Results of Site-Specific Management

Construction of a nutrient management database made it possible

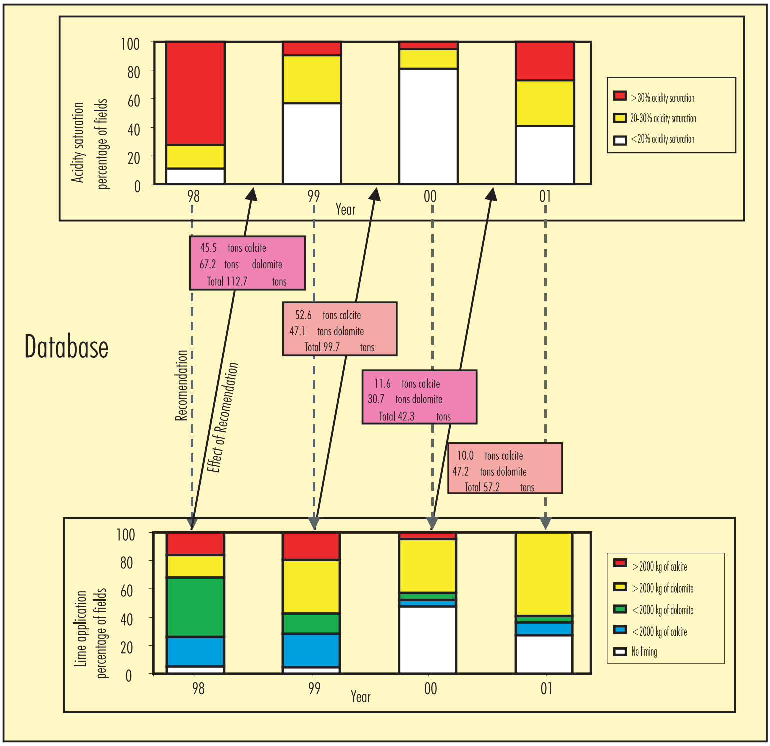
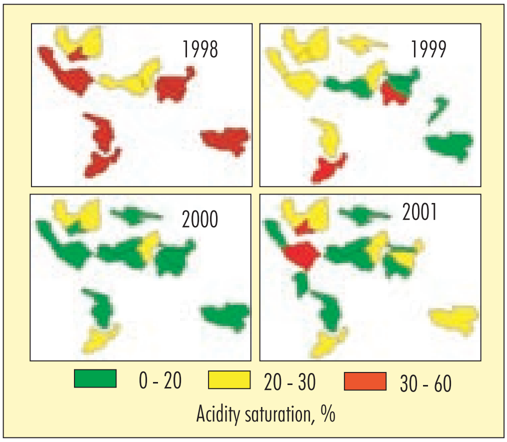


Figure 1. Distribution of acidity saturation on coffee fields in El Sitio, Viñas, Costa Rica.

for researchers to isolate the main nutritional problems at field scale. For example, database results (not fully presented) indicated that soil acidity problems were more intense in some fields and not present in others. This problem has been controlled over the years by calcite application based on average soil test results. Using this approach, based on the liming recommendations for tropical volcanic soils, more than 2,000 kg lime/ha would be needed for all fields. It was clear that site-specific management was the best way to approach this problem.

The effect of site-specific management of acidity is presented as the percentage of fields affected by different degrees of acidity, the amount of lime used to solve the problem, and the treatment's effect in the following year (**Figure 1**). The rate of lime applied equaled the amount needed to reduce the percentage of acidity to 15 percent and dolomite was applied when the magnesium (Mg) soil test was less than 0.6 cmol$_{(+)}$/L.

Figure 2. Effect of site-specific management on acidity saturation in coffee fields of El Sitio farm, Viñas, Costa Rica.



The trends can be observed when data are applied to Geographic Information System (GIS) software (**Figure 2**). The effect of this type of management on soil acidity is also observed in the average soil test results for each year of the study (**Table 3**), and demonstrate the effect of site-specific management for the whole coffee and sugarcane area.

The effect of controlling acidity problems in coffee is evident. However, lime application increased in 2001, which was the result of less than optimal liming rates in 2000 due to economic limitations of low coffee prices. The GIS can assure constant monitoring of the situation and management decisions can

Table 3. Average soil test results for coffee fields from 1999 to 2001, El Sitio farm, Viñas, Costa Rica.

Year	pH	Acidity saturation, %	ECEC	Total acidity	Ca	Mg	K	P	Mn	Zn
			- - - - - - - - - - -	- - - - - - - - - - -	cmol$_{(+)}$/L	- - - - - - - - - - -		- - - - -	mg/L	- - - - -
					Coffee					
1997	4.6	29	11.62	3.1	7.15	0.75	0.62	50	17	3
1998	4.7	33	5.62	1.9	3.02	0.70	0.31	25	9	2
1999	4.9	17	7.76	1.1	5.13	1.00	0.53	25	17	4
2000	5.1	11	8.39	0.7	5.81	1.27	0.61	31	9	7
2001	5.1	19	7.13	1.0	4.70	0.99	0.49	33	7	4
					Sugarcane					
1998	5.2	17	3.85	0.7	2.78	0.21	0.18	8	6	2
1999	4.7	15	4.43	0.6	3.18	0.43	0.18	14	6	3
2000	5.2	11	3.62	0.4	2.80	0.35	0.11	7	6	1
2001	5.5	10	4.90	0.5	3.78	0.50	0.16	21	10	4

be derived from this accurate knowledge base.

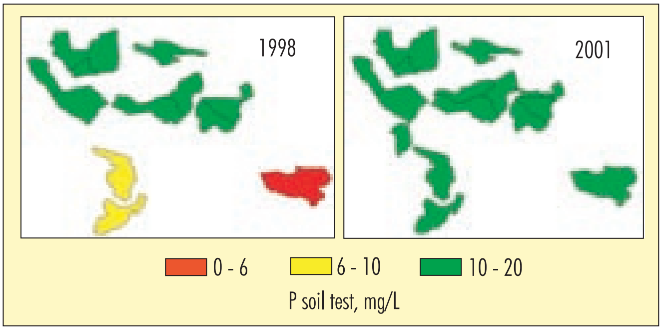


Figure 3. Effect of site-specific management on P soil test in coffee fields of El Sitio farm, Viñas, Costa Rica.

Control of soil acidity affects root performance and nutrient uptake which, in turn, promotes greater nutrient use efficiency. Site-specific management also improved the fertilizer recommendation system. Two or three different nutrient application options are designed each year for coffee and sugarcane based on nutrient requirements and the soil test results of each field. The effect of nutrient application is recorded in the database and management is normalized by the conditions of each field. The effect of site-specific management on soil P is shown in **Figure 3**.

Finally, other important decisions can be made based on the information accumulated in the database. Disease problems like Corchosis (a condition caused by an interaction of *Meloidogyne arabica* and *Fusarium spp*), can be monitored and managed. Pruning and harvesting management can be improved using the information accumulated over the years. The system of harvesting is the major problem in terms of constructing a reliable database in crops like coffee where fruit collection is a manual operation. As well, imaginative recording methods for the harvested products are being developed to take advantage of the information provided by yield responses to different crop and nutrient management strategies. **BCI**

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

By C. Witt and A. Dobermann

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

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

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

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

Step 1: Yield goal selection

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

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

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

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

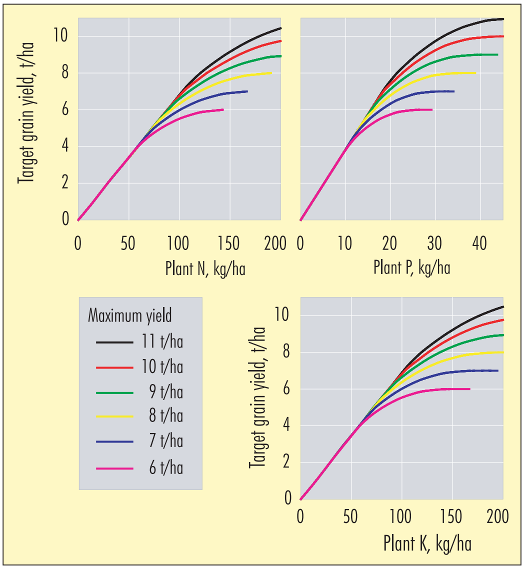
Step 2: Estimation of crop nutrient requirements

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

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

Plant nutrient requirements for a particular yield goal may be smaller in a high yielding season than in a low yielding one. For example, 80 kg plant N would be

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



Nitrogen omission plot embedded in a farmer's field.

required to support a yield goal of 5.5 t/ha at a Y_{max} of 10 t/ha, but 100 kg plant N would be required for the same yield goal at a Y_{max} of 6 t/ha (**Figure 1**). The model also provides a useful tool for identifying optimal yield goals based on the relationship between grain yield and nutrient uptake.

Step 3: Estimation of indigenous nutrient supplies

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

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

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

Step 4: Calculation of fertilizer rates

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

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

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

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

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

Step 5: Dynamic adjustment of fertilizer N applications

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

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

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

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

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

Conclusions

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

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Performance of Site-Specific Nutrient Management in Intensive Rice Cropping Systems of Asia

By A. Dobermann, C. Witt, and D. Dawe

A site-specific approach to nutrient management was evaluated in 179 on-farm experiments with irrigated rice in China, India, Indonesia, Thailand, the Philippines, and Vietnam. The agronomic and economic performance of the new approach was compared with current farmer fertilizer practices for four crops.

Soil nutrient supplies, fertilizer efficiency, and productivity vary widely across small distances in the diverse irrigated rice fields in Asia. At present, however, blanket fertilizer recommendations are often applied over large areas without taking into account the wide variability and site- and season-specific crop nutrient requirements within each recommendation domain. This helps to explain why fertilizer nitrogen (N) use efficiency is usually poor, the use of potassium (K) fertilizers is often not balanced with crop requirements and other nutrients and, as a result, profitability is not optimised (Dobermann et al., 1998; Olk et al., 1999).

Based on these conclusions, drawn from three years of on-farm research in five Asian countries, the International Rice Research Institute (IRRI) together with National Agricultural Research and Extension Systems (NARES) partners launched a research project in 1997 to develop site-specific nutrient management (SSNM) technology for intensive rice systems (Witt and Dobermann, this issue). A series of on-farm experiments was conducted in six Asian countries to test the hypothesis that rice yields, profit, plant nutrient uptake, and fertilizer efficiencies can be increased significantly through field- and cropping season-specific nutrient management. In this article, we evaluate the performance of SSNM compared to prevailing farmer practices.

Materials and Methods

On-farm experiments were conducted in major rice production domains with at least two rice crops per year in Jinhua (Zhejiang, China), Maligaya (Nueva Ecija, the Philippines), Suphan Buri (Thailand), Omon (Mekong Delta, South Vietnam), Hanoi (Red River Delta, North Vietnam), Sukamandi (West Java, Indonesia), and Aduthurai and Thanjavur (Tamil Nadu, South India). The experimental set-up followed a

Table 1. Plant-based estimates of potential soil indigenous N, P, and K supplies derived from omission plots (179 farms, two seasons) in 1997-1998.

	Minimum	25% quartile	Median	75% quartile	Maximum
Plant N uptake in 0-N plots, kg/ha	29	52	64	76	107
Plant P uptake in 0-P plots, kg/ha	7	14	17	20	32
Plant K uptake in 0-K plots, kg/ha	43	74	90	109	198
Grain yield 0-N plots, t/ha	1.8	3.8	4.5	5.2	6.5
Grain yield 0-P plots, t/ha	2.7	4.5	5.7	6.7	8.2
Grain yield 0-K plots, t/ha	2.6	4.6	5.6	6.6	8.8

standard protocol at all sites and included nutrient omission plots (0-N, 0-P, 0-K) to estimate indigenous nutrient supplies, a SSNM treatment, and farmer fertilizer practice (FFP) in each farmer field. Researchers did not intervene in the FFP plots but managed fertilizer application in the SSNM and nutrient omission plots. Farmers were responsible for all other aspects of general crop and pest management and the choice of variety. Treatments (SSNM and FFP) were compared on 179 farms over a period of four cropping seasons during 1997 to 1999 (Dobermann et al., 2002a; 2002b).

An estimate of soil indigenous N, phosphorus (P), and K supply was obtained from omission plots situated in each farmer field. The results from these plots were used as inputs in a model designed to estimate field-specific fertilizer requirements in the SSNM plots (Witt and Dobermann, this issue).

Soil nutrient supplies varied widely, and two- to three-fold ranges were found for each nutrient and site (**Table 1**). Average soil nutrient supplies, based on measurements of plant nutrient uptake at all sites, were 64 kg N, 17 kg P, and 90 kg K per ha per crop. Over all sites, grain yield without N application ranged from less than 2 t/ha to more than 6 t/ha, with a median of 4.5 t/ha. Average grain yield in 0-P and 0-K plots was about 5.7 t/ha, but soil P and K supplies were sufficient for grain yields of only 4.5 t/ha on 25 percent of the farms. For comparison, current average yields in irrigated rice are about 5.3 t/ha. While these results confirm the primary importance of N in irrigated rice, P and K appear to be equally limiting in many parts of South and Southeast Asia.

Table 2. Agronomic and economic performance indicators.

Indicator	Unit	Interpretation
Increase in grain yield	t/ha or %	Gross productivity
Achievement of yield goal	% of yield goal	Climatic variability and quality of crop management
Internal nutrient efficiency	kg/kg	Balanced nutrition within the plant, occurrence of other stresses
Nitrogen use efficiency (AEN, PEN, REN)	kg/kg	Congruence of N supply and crop N demand; negative effects on the environment
Input-output balance of P and K	kg/ha/crop	Medium- and long-term sustainability of soil productivity
Gross return over fertilizer cost (GRF)	US$/ha/crop	Financial profitability

Performance indicators were used for the agronomic and economic evaluation of SSNM and FFP (**Table 2**):

- Internal N efficiency (IEN) is the grain yield produced per unit N taken up by the plant (kg grain/kg plant N).
- Recovery efficiency of fertilizer N (REN) is the increase in plant N uptake per unit fertilizer N applied (kg plant N/kg fertilizer N).

- Physiological N efficiency (PEN) is the increase in grain per unit increase in plant N uptake from fertilizer (kg grain/kg plant N).
- Agronomic N use efficiency (AEN) is the product of REN and PEN, expressed as the yield increase per unit fertilizer N applied (kg grain yield/kg fertilizer N).
- Gross return over fertilizer costs (US$/ha/crop) is calculated as revenue (grain yield x farm gate paddy price) minus fertilizer cost.

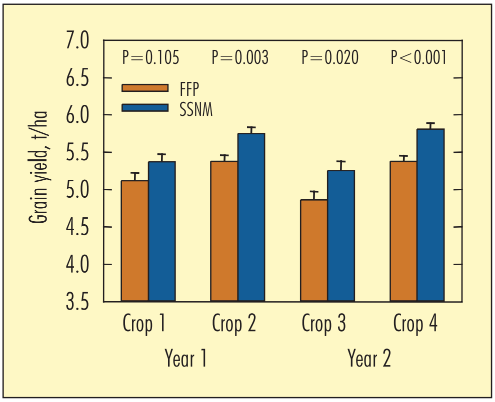
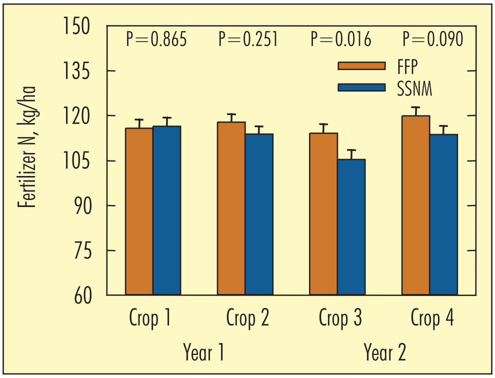


Figure 1. Grain yield (means, standard errors) in FFP and SSNM treatments, 1997-1999.

Results and Discussion

The average grain yield increase was 0.36 t/ha or 7 percent greater with SSNM compared to the FFP (**Figure 1**). Yield advantages with SSNM were similar in both high and low yielding seasons, and increased due to greater experience from 0.31 t/ha in the first year (+6 percent) to 0.41 t/ha in the second year (+8 percent). With the exception of the first crop, grain yields in SSNM plots were consistently higher compared with the FFP treatment. The probability of a yield increase was 73 percent, with no difference between high and low yielding seasons. Plant uptake of N, P, and K was greater with SSNM compared with FFP.

Figure 2. Fertilizer N use (means, standard errors) in FFP and SSNM treatments, 1997-1999.



The *total* amount of fertilizer N applied was initially similar in the two treatments, but N rates were about 7 percent lower in SSNM in the second year (crops 3 and 4, **Figure 2**). Fertilizer N management in SSNM and FFP differed mainly in terms of the splitting and timing of N fertilizer. Fertilizer N was applied more frequently in SSNM with an average of 3.1 applications per crop in SSNM compared to 2.6 in FFP (most farmers applied fertilizer N early in the season, when the capacity for efficient N recovery is small). Under SSNM, N applications were typically delayed by five to six days compared to FFP and the average fertilizer N split in SSNM was about 10 kg N/ha or 25 percent less than in FFP.

Fertilizer P and K rates in SSNM were adjusted over the four seasons. Application rates were reduced in the second season as more data from nutrient omission plots became available to fine-tune the Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model. Differences among treatments in fertilizer P rates were generally small and decreased over the four crops (**Figure 3**). Fertilizer K rates predicted by the model to achieve target yields and maintain the soil indigenous K supply were, on average, higher than the amounts

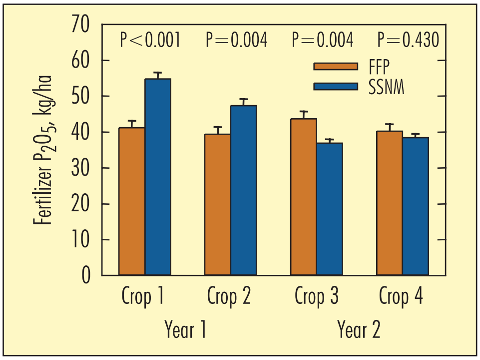


Figure 3. Fertilizer P_2O_5 use (means, standard errors) in FFP and SSNM treatments, 1997-1999.

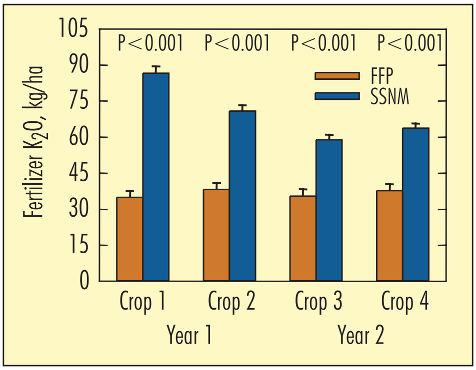


Figure 4. Fertilizer K_2O use (means, standard errors) in FFP and SSNM treatments, 1997-1999.

currently applied by farmers (**Figure 4**). Potassium rates in SSNM were adjusted from 79 kg K_2O/ha/crop in the first year to 61 kg K_2O/ha/crop in the second year, while the average farmer fertilizer K_2O rate remained unchanged at about 37 kg K_2O/ha/crop.

Recovery efficiency of fertilizer N increased significantly with SSNM (**Table 3**). On average, REN increased by about 29 percent with SSNM (40 percent) compared to FFP (31 percent). There was no difference among treatments in PEN, indicating that plants in both treatments transformed fertilizer N into grain yield with equal efficiency (PEN about 36 kg/kg). Agronomic N use efficiency was greater with SSNM (14.8 kg grain/kg fertilizer N) than FFP (11.5 kg grain/kg fertilizer N) due to greater REN in the SSNM treatment. The improved synchrony between plant N demand and supply from soil and fertilizer was probably the main cause of increased uptake of N, P, and K and the observed yield increase in SSNM.

Internal N efficiency in SSNM reached 57 kg grain produced per kg plant N uptake (**Table 3**), which is 85 percent of the theoretical optimum of 67 kg/kg that can be achieved with optimal crop and nutrient management (Witt et al., 1999). The conversion rate of nutrient uptake to grain yield was similar for P and K, and the difference between SSNM and FFP treatments was small. This suggests that the occurrence of stress factors other than nutrient supply was probably similar in the two treatments and that there is potential to further increase yield at the same level of nutrient uptake. More detailed analysis indicated that while nutrient uptake was sufficient to achieve the yield goal (set at almost 80 percent of the yield potential), actual yields in SSNM were about 67 percent of the po-

Table 3. Effect of SSNM on N use efficiencies in 179 irrigated rice fields of Asia (four crops in 1997 to1999).

		Treatment			
	Levels[a]	SSNM	FFP	Δ[b]	P>|t|[b]
Internal efficiency,	All	56.9	58.6	-1.7	0.004
(IEN, kg grain/kg	HYS	57.5	59.0	-1.5	0.070
plant N)	LYS	56.2	58.2	-2.0	0.025
Agronomic efficiency,	All	14.8	11.5	3.3	<0.001
(AEN, Δkg grain/kg	HYS	16.2	12.7	3.5	<0.001
fertilizer N)	LYS	13.4	10.3	3.1	<0.001
Recovery efficiency,	All	0.40	0.31	0.09	<0.001
(REN, Δkg plant N/kg	HYS	0.44	0.36	0.08	<0.001
fertilizer N)	LYS	0.37	0.28	0.09	<0.001
Physiological efficiency,	All	37.2	36.3	0.9	0.320
(PEN, Δkg grain/Δkg	HYS	37.6	36.1	1.5	0.226
plant N)	LYS	36.9	36.6	0.3	0.809

[a] All - four crops; HYS – High yielding season; LYS – Low yielding season.

[b] Δ is the difference between SSNM and FFP; P>|t| - probability of a significant mean difference between SSNM and FFP.

tential yield compared to 62 percent in FFP. It is likely that further yield increases will only be achieved if other crop management factors are also improved.

Nutrient balances were constructed for P and K, based on fertilizer inputs and nutrient removal with grain and straw, for the four crops grown between 1997-1999 (**Figure 5**). The average input-output balance for P was positive in 75 percent of all farms and averaged less than 5 kg P/ha/crop. There were no differences between SSNM and FFP and this suggests that the average fertilizer P use of about 40 kg P_2O_5/ha/crop appears to be sufficient to support current average yields and sustain a small positive P balance in the soil in most farms. The average K balance, however, was negative in FFP because insufficient fertilizer K was applied to replace the amount removed in the crop and straw. Potassium balances were negative on 80 percent of all farms and averaged about -25 kg K/ha/crop. The negative K balance was reversed with SSNM in many farms, and site-specific K management reduced the average K balance to about -5 kg K/ha/crop.

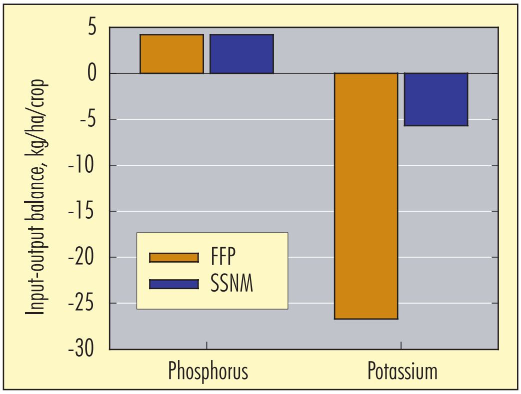
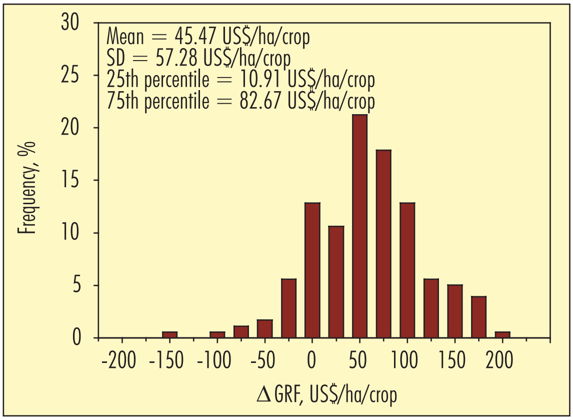


Figure 5. Estimated average input-output balance of phosphorus and potassium in FFP and SSNM treatments after four consecutive crops, 1997-1999.

When averaged over four crops and all sites, financial profitability of rice farming in SSNM was increased by about US$45/ha/crop compared with FFP (**Figure 6**). Average net return (total revenue minus total costs) was estimated at about US$400/ha/crop; SSNM increased net returns by about 12 percent. Site-specific nutrient management was profitable for almost 80 percent of farmers when averaged over four cropping seasons. There were substantial differences in profitability among sites. Good general crop care is needed to realize the full benefits of improved nutrient management strategies.

Figure 6. Farm-specific financial profitability of SSNM over FFP (increase in gross return over fertilizer cost due to SSNM, ΔGRF), average of four crops, 1997-1999



Conclusions

Field-specific management of macronutrients increased yield by seven percent and profitability by 12 percent on 179 rice farms in Asia. Increased nutrient uptake and N use efficiency across a wide range of rice growing environments with diverse climatic conditions were related to the effects of improved N management and balanced nutrition. A major challenge is to simplify the approach for wider scale dissemination without sacrificing components that are crucial to its success. The underlying principles of SSNM need to be carefully identified and evaluated for each macronutrient. Approaches to further dissemination must be related to prevailing site-specific conditions.

A limited number of well-positioned nutrient omission plots in a particular domain provide sufficient information on soil nutrient supplies to develop improved nutrient management strategies, particularly for the less limiting nutrients, P and K. The many theoretical and technical limitations of soil-test based approaches may therefore be overcome by simple and robust plant-based indicators of nutrient supply such as grain yield in omission plots and leaf color. Leaf color charts can be used as an on-farm guide for N management, since field-specific decisions for N management are probably required to achieve the best match between highly variable plant N demand and fertilizer N application. Results suggest that further increases in yield can only be expected when the farmer exploits the synergy that occurs when *all* aspects of crop, nutrient, and pest management are improved simultaneously. However, this sample of farmers achieved relatively high average rice yields representative for the intensive, irrigated lowland conditions in which future yield increases are likely to be achieved only in smaller increments. **BCI**

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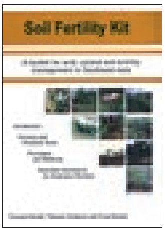
Soil Fertility Kit – A Toolkit for Acid Upland Soil Fertility Management in Southeast Asia



This new 159-page handbook is a compendium of information and methods for managing upland soil fertility in Southeast Asia. Titled *Soil Fertility Kit*, the publication is in an easy to read format useful for extension workers, farmers, and researchers. It is authored by Thomas S. Dierolf, Thomas H. Fairhurst, and Ernst W. Mutert. Dr. Fairhurst and Dr. Mutert are Directors, PPI/PPIC East and Southeast Asia Program (ESEAP), Singapore.

Part 1 of the book presents practical tools and participatory approaches for investigation and diagnosis of soil fertility problems in acid, upland soils. Part 2 provides information on the chemical, physical, and biological properties of such soils and the major causes of problems. Nutrient cycles, integrated nutrient managements, and biological soil fertility management are discussed. Part 3 is a compilation of essential information on soil classification, soil/plant sampling and testing, critical soil/plant nutrient levels, nutrient uptake and removal in crops, and fertilizer recommendations.

The book can be purchased for US$35.00 per copy, including shipping/handling. Discounts are available on bulk quantities. For more details, visit the website at www.eseap.org, or contact Doris Tan, PPI/PPIC (ESEAP), 126 Watten Estate Road, Singapore. 287599. E-mail: dtan@ppi-ppic.org, phone +656 468 1143, or fax +656 467 0416.

Potassium and Chloride in Crops and Soils Publication Available as IPI-Research Topics No. 22

Potassium chloride (KCl) is commonly known in agriculture as muriate of potash (MOP), the major potassium (K) fertilizer used in crop production. When applied properly with other essential nutrients, K has numerous benefits affecting yield, quality, and stress resistance of crops.

However, there is still widespread imbalance in K use, with negative balances in many cropping systems in most regions of the world. The accompanying element in MOP, the chloride (Cl^-) ion, is an essential plant nutrient required in small amounts. Concern is sometimes raised about its role in soil salinity.

A new publication from the International Potash Institute (IPI) describes in detail the functions of K and Cl^- in plants and their importance to crop production. Titled *Potassium and Chloride in Crops and Soils: The Role of Potassium Chloride Fertilizer in Crop Production*, the 220-page booklet is identified as IPI-Research Topics No. 22. It is available for the price of US$14.00.

For more information, contact the International Potash Institute, P.O. Box 1609, CH-4001 Basel, Switzerland; telephone +41 61 261 29 22, fax +41 61 261 29 25, e-mail: ipi@iprolink.ch, on through the website at www.ipipotash.org.

You are now entering an Oxygen Enrichment Zone … a farm.

What an interesting and positive twist to global greenhouse gas concerns…and the Kyoto Accord. It is a powerful statement about agriculture and its environmental role and contribution. The power of the statement first comes from the scientific truth: that through photosynthesis, carbon dioxide is fixed and oxygen is released; and secondly, from the optimism it states. Agriculture's leaders and practitioners…the researchers and farmers…operate and prosper according to their measure of optimism and their adherence to scientific truth.

The message underlying this thought, '*You are now entering an Oxygen Enrichment Zone*', is that good agriculture means a healthy and vibrant environment. Who would have thought that agriculture's message to urban dwellers could be delivered with such brevity and clarity? This truism certainly puts to flight the environmentalist's castigating message of progressive agriculture as a polluting and environment-destroying activity.

Let's think about agriculture and how over the years, with improved availability of inputs, technology, and management, it has benefited the world we live in. Progressive agriculture reduces the need to farm … or allows reclamation of … environmentally fragile landscapes which provide habitat for wildlife and sustains biodiversity. Progressive agriculture uses water efficiently, thereby reducing soil erosion and further stabilizing the environment. Progressive agriculture builds and restores the soil's fertility and tilth, or soil quality, which is vital to sustain our food supply. The sum total of progressive agriculture: appropriate use of the world's resources to improve crop yields—which fixes more carbon dioxide and releases more oxygen—which sustains people and the quality of the air we breathe.

Progressive agriculture—-*You are now entering an Oxygen Enrichment Zone.* And, with thanks to farmers and researchers from around the globe, let me say this: You are making *this world* a better place.

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