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Our Cover: Intensive management on small land holdings in Yunnan Province, China.

Photo Source: Dr. S.S. Portch

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A Site-Specific Nutrient Management Approach for Maize

By Tasnee Attanandana and R.S. Yost

Extension workers in Thailand are being trained to use handheld computers for calculating nitrogen (N), phosphorus (P), and potassium (K) fertilizer requirements for maize. A simplified soil test kit was developed for rapid NPK measurement in the field. A farmer network has been established to exchange information, equipment, and labor.

Fertilizer recommendations in Thailand are obtained from simple experiments and extrapolated on generalized soil properties. Recent research using the Decision Support Systems for Agrotechnology Transfer (DSSAT-CERES-Maize) and the Phosphorus Decision Support System (PDSS) together with simplified soil test kits resulted in higher yields, greater economic return, and balanced fertilization. This technology was developed and tested in the maize belt area of four provinces in Thailand. More than 200 farmers and about 1,000 extension workers and academic officers have been trained in the approach. And more than 10,000 kits are being used by extension workers, academic officers, and farmer leaders.

Maize is an important crop in Thailand, with about 1.7 million hectares (M ha) in production, mainly for use in animal feed. The government of Thailand wishes to increase productivity and total production of maize as part of its efforts to improve food security and farmer incomes, particularly in the maize belt (Lop Buri, Nakhon Sawan, Petchaboon, and Nakhon Ratchasima provinces) where about 0.5 M ha or 30% of the total crop is cultivated. The average maize farm size in Thailand is about 10 ha and the national average yield is presently about 3.7 t/ha (Agricultural Statistics, 2001), but larger yields of >6.0 t/ha have been obtained in experimental plots (Attanandana et al., 2000).

Application of adequate quantities of plant nutrients is a key aspect of increasing maize productivity and production, particularly where farmers use hybrid maize with high yield potential. At present, recommendations supplied to farmers are very general (and often constrained by the nutrient content of particular fertilizer compounds available on local markets) rather than related to site-specific crop nutrient requirements. In addition, most existing fertilizer spreaders were not adjustable (Attanandana, et al., 2002a). These factors result in unbalanced and inefficient fertilizer use that results in poor economic returns to the farmer and inefficient use of costly imported fertilizer materials. Furthermore, when N and P are used in unbalanced nutrient programs, they may be in excess of crop demand and result in losses from the soil-crop system, contributing to the nutrient load in streams, rivers, and other water bodies. Unbalanced fertilizer use also causes soil degradation, particularly when N fertilizer use drives the removal of P and K that are not replenished by the addition of fertilizer nutrients.

Thus, there is an urgent need for more site–specific nutrient recommendations that can be readily transferred to farmers by extension officers or farmer leaders and which meet farmers' production goals and resources. Soil testing is an important tool for preparing site–specific fertilizer recommendations, but is little used by farmers due to the lack of supportive research, the cost of soil analysis, and the limited capacity for soil testing at province level which results in an unacceptable delay between the time of soil sampling and the delivery of recommendations to farmers. Also, farmers not skilled in the selection of suitable fertilizer materials often fall prey to poor advice. To address these needs and problems, a program of revising fertilizer recommendations was begun in Thailand in 1998 with the first Thailand Research Fund project. The following steps were undertaken to revise the fertilizer recommendation program.

Photo 1.

Photo 2.

A Step-Wise Approach to Fertilizer Recommendations

Step 1. Soil test kit development. A simple test kit (**photos 1 and 2**) was developed for rapid analysis of soil pH, N, P, and K. The kit uses colorimetric tests with droppers to apply indicator solutions, calibrated scoops to measure the sample, and plastic bottles to prepare samples for analysis. Comparisons of the kit's rapid soil test methods (**Table 1**) with conventional methods indicated strong agreement in all tests for analysis of nitrate (NO_3^-), 80% of tests for P, 90% of tests for K (Attanandana et al., 2002b).

Step 2. Simplified method to identify the soil series. Soil chemical and physical properties not measured by the soil test kit were estimated based on the local soil series. Extension workers and farmer leaders were trained to identify the soil series by using a simple key contained in a pocket guide. Thus, soil characteristics such as pH, texture, color, presence or absence of gravel at particular depth, free calcium carbonate, and soil depth were based on information contained in the key. Soil series identification and the comparison of different soil series were performed by reference to illustrations of the soil profiles for each soil series contained in the pocket guide (**photos 3a and 3b**).

Photo 3a, left.
Photo 3b, right.

Table 1. Comparison of soil test data by test kit and laboratory determination.									
	NO_3^- content			P content			K content		
Soil	Spectro (Mehlich)		Soil	Spectro (Mehlich)		Soil	Atomic absorption		Soil
series	mg N/kg	Level	test kit	mg P/kg	Level	test kit	mg K/kg	Level	test kit
Lb1	2.00	VL	VL	4.50	M	H*	80	M	M
Lb2	18.00	L	L	0.25	VL	VL	130	H	H
Lb3	3.47	VL	VL	3.50	M	M	82	M	M
Ln1	4.38	VL	L	6.75	M	H*	89	M	M
Ln2	4.37	VL	VL	1.00	L	L	71	M	M
Tk1	2.67	VL	L	3.25	L	L	277	H	H
Tk2	12.92	L	L	0.56	L	VL	174	H	H
Pc	7.00	VL	L	6.00	M	M	39	L	L
Ct	3.00	VL	VL	2.00	L	L	266	H	M*
Lb	18.00	L	L	19.60	VH	H	628	H	H

* Indicates a significant difference between conventional and soil test kit methods.

Step 3. Simplification of crop modeling software for NP estimation. After the soil series has been identified, and the appropriate soil and weather data loaded, the DSSAT–CERES–Maize software (version 3.0) (Tsuji et al., 1994) can be used to predict maximum economic yield and maize N requirements. The PDSS was used to estimate P fertilizer requirements based on buffer coefficients, which are a simple function of soil clay percentage (Cox, 1994). These coefficients, together with estimates of field soil test P levels, were used to estimate fertilizer P requirements (Yost et al., 1992). Recommendations for N and P (type of fertilizer, amount required, and application timing) were printed in a manual for use by extension workers and farmer leaders.

Predicted and measured yield of Suwan 3601 hybrid maize was compared on important soils in four provinces of the maize belt area with NPK fertilizer recommendations based on the procedure described above. Relative yield was used to compare measured yield with the yield predicted by the model (Willmott, 1982). In eight experiments, the agreement index ranged from 0.90 to 0.99, indicating a close agreement between the predicted and actual yield for seven soil series (Attanandana et al., 2002b). The test kit results indicated very low soil N and P levels and the decision-aids predicted that larger amounts of fertilizer N and P were needed than in farmer practice. Field results indicated that the decision-aids fertilizer predictions resulted in higher

Table 2. Comparison of NPK fertilizer recommendation, yield of maize using decision aids and farmer's practice, and predicted economically optimal yields estimated by DSSAT 3.0.								
				Recommendation N–P–K		Yield, t/ha		
Soil series	pH	Soil texture	Nutrient level, N–P–K	Farmer practice	CERES maize PDSS	Farmer practice	CERES maize PDSS	Predicted optimal yields
Lampayaklang	7.5	Clay	VL–VL–H	25–25–0	94–44–0	2.78	6.06	5.5
Chatturat	7.0	Loam	VL–VL–H	19–25–0	94–50–0	2.93	4.47	7.0
Lop Buri	8.0	Clay	VL–VL–H	69–38–0	125–69–0	2.71	3.43	6.9

Table 3. Economic analysis of maize production using decision-aids and farmer practice.

Treatment	Profit, US$/ha[1]
Farmer practice	261.3 a*
CERES- MB[2]	316.1 b
CERES-PDSS-MB	319.6 b

[1]US$1 = 43 baht
*Numbers followed by the same letter are not significantly different at p=0.05.
[2]MB=Mitscherlich-Bray

yields when compared with the farmer practice (**Table 2**). Farm profit was increased when the soil test kit and decision aids were used to prepare fertilizer recommendations despite increased fertilizer costs (**Table 3**).

Step 4. Farmer learning. A Participatory Learning Forum (PLF) was a successful method to identify and select farmer leaders. Farmers were asked to identify the leaders in the community, identify the best and most knowledgeable maize farmers, estimate the area and yield of maize in the local community, and determine price of maize, cost of fertilizer, and investment opportunities in the local community.

Photo 4.

Those who completed this work were selected for further contact. Farmers responded very favorably by taking the initiative to form their own network, with extension workers. **Photo 4** shows farmers discussing and solving their problems.

Step 5. Refining the N simulation. The CERES-Maize version 3.0, was initally simplified to estimate N fertilizer requirements based on the amounts of soil organic carbon from the laboratory data for each reference soil profile. This simplification was modified for DSSAT 3.5 to directly use the soil NO_3^- test results from the test kit. Other parameters used by the model were also adjusted: rooting depth of maize was reduced to 50 cm, allowance was made for the addition of 3 t/ha of crop residues, and the increment of N fertilizer was reduced to 10 kg/ha. An N response curve was developed on the farmers' fields by including a check and several levels of applied N that were greater and smaller than the amount recommended by the decision-aids. This response is being used to evaluate current predictions by DSSAT version 3.5 and plan for further revisions. There were relatively large differences between the N fertilizer recommendations produced by DSSAT version 3.0 and version 3.5 (**Table 4**).

Table 4. Nitrogen fertilizer recommendations and predicted economically optimal yield (maize variety Suwan 3601) for three soil series using DSSAT V 3.0 and 3.5.

		DSSAT V 3.0		DSSAT V 3.5	
Soil series	Nitrate level	N requirement, kg/ha	Predicted yield, t/ha	N requirement, kg/ha	Predicted yield, t/ha
Cd	Very low	95	6.97	90	7.45
	Low	65	6.96	80	7.54
	Medium	35	6.92	40	7.51
Pc	Very low	95	7.21	70	7.28
	Low	35	6.93	30	7.24
	Medium	35	7.18	20	7.28
Suk	Very low	125	6.46	140	7.83
	Low	35	6.07	100	7.66
	Medium	35	6.51	90	7.73

Conclusions

After training and with guidance from extension workers, farmers were able to identify the soil series using a pocket guide and determined basic soil fertility with a simple soil test kit. Nitrogen and P fertilizer requirements for maize, predicted by DSSAT-CERES and PDSS, respectively, resulted in increased yields and farm profits. The DSSAT 3.5 software predicted N fertilizer requirements based on soil NO_3^- measured with the soil test kit before planting and the model allowed for the effect of rainfall on possible N losses due to leaching (based on historical rainfall distribution), and the supply of N from soil and crop residues.

The PLF proved to be a major success in stimulating the farmers to organize and think for themselves. Farmers were able to determine their fertilizer requirements and formed networks to share resources and information. **BCI**

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Workshop Set for August 2003

The use of soil test kits to improve fertilizer recommendations for maize growers will be the subject of a workshop at Kasetsart University, Bangkok, Thailand, in August 2003. More details are available at www.eseap.org.

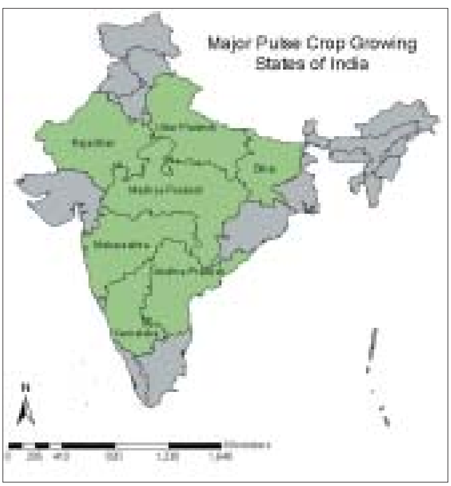
Potassium Requirements of Pulse Crops

By Ch. Srinivasarao, Masood Ali, A.N. Ganeshamurthy, and K.K. Singh

In India, pulses are grown mostly on marginal and sub-marginal lands without proper inputs. Potassium (K) is rarely applied to these crops despite larger K requirements of pulses and continued mining of soil K. Many field experiments on various pulse crops show yield benefits from K application. Improved K supply also enhances biological nitrogen (N) fixation and protein content of pulse grains.

Chickpea, pigeonpea, urdbean, mungbean, mothbean, horsegram, lentil, pea, rajmash, and lathyrus are important pulse crops grown in India, occupying about 23 million hectares (M ha). The productivity of pulse crops is low for two reasons: cultivation on agriculturally marginal soils, and little if any crop inputs. Among production inputs, fertilizer plays a key role in enhancing productivity levels. Pulse crops fix atmospheric N, the predominant mechanism to meet their N requirement. However, this capability is jeopardized through insufficient supply of plant nutrients. General recommendations for phosphorus (P) fertilization are made in most states. However, K application is generally neglected, resulting in imbalanced nutrient supply and lower crop yields. Under intensive cropping systems, large amounts of K are removed, leading to serious depletion of soil K reserves. Pulses such as chickpea and pigeonpea remove about 60 and 52 kg K_2O/t grain, respectively.

The major pulse crop growing states in India are noted in the accompanying map. Soil types differ among these agro-ecological regions and include alluvial soils, medium and deep black soils, and red and lateritic soils (Subba Rao and Srinivasarao, 1996). Potassium status of these soils varies considerably depending on parent material, texture, and management practices. In general, black soils with smectite as a dominant clay mineral have higher clay percentage, cation exchange capacity (CEC), and exchangeable K, and medium to high levels of non-exchangeable K. Lighter-textured alluvial soils with higher contents of K-rich mica have moderate levels of exchangeable K and high levels of non-exchangeable K. Lighter-textured red and lateritic soils with kaolinite as the dominant clay mineral are low in both exchangeable and non-exchangeable K (Ali and



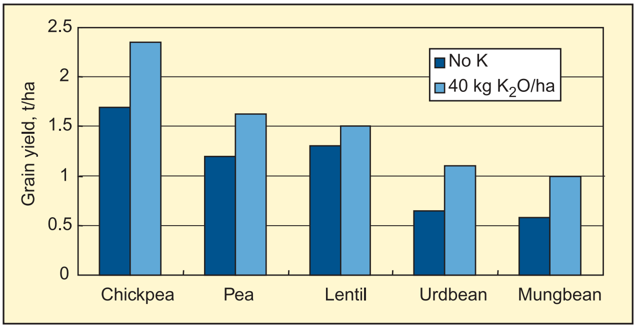


Figure 1. Effect of K application on grain yield of different pulse crops (Tiwari and Tiwari, 1999).

Srinivasarao, 2001).

The pattern and extent of pulse crop response to K fertilizer depends on yield potential, soil K status, genotype, and supply of critical inputs such as irrigation and other nutrients.

Compared to a zero K treatment, application of 30 kg K_2O/ha enhanced chickpea, pea, and lentil grain yields by 21, 25, and 24%, respectively, on a Typic Ustochrept soil in Kanpur (Tiwari and Nigam, 1985). Application of 60 kg K_2O/ha, produced respective yield increases of 23, 37, and 32%. The study reported higher K responses in pulses compared to cereal or oilseed crops and postulated that well branched root systems of cereal and oilseed crops might exploit soil K more efficiently than pulse crop root systems. Studies conducted under the All India Coordinated Research Project (AICAR) also found a significant grain yield response to K in lentil at Ludhiana, Pantnagar, and Ranchi (PRII, 1999). A study on effect of K application (40 kg K_2O/ha) along with rhizobium culture on different pulse crops resulted in substantial yield gains due to K (**Figure 1**) (Tiwari and Tiwari, 1999).

In 205 chickpea field trials conducted in various districts of Uttar Pradesh, application of 20 kg K_2O/ha increased grain yield by 95 kg/ha over check K plots receiving only 20-40 kg N-P_2O_5/ha (**Table 1**) (Yadav et al., 1993). At the lowest K rate, 20 kg K_2O/ha, the average chickpea grain yield response was 4 kg grain per kg K_2O. The range of lentil responses to K was between 3 to 16 kg grain per kg K_2O. Average pigeonpea and pea responses to 20 kg K_2O/ha were 14 and 7 kg grain per kg K_2O, respectively. In a separate study, an average increase of 5 kg grain per kg K_2O was recorded for chickpea in northern states of India. It should be noted that economic response to 40 kg P_2O_5 was apparent in lentil, pigeonpea, and pea, while in chickpea and urdbean, economic responses were recorded at 30 and 20 kg P_2O_5/ha.

Table 1. Response of pulses to K on cultivators' fields under rainfed condition (Yadav et al., 1993).

Crops	No. of trials	Grain yield response to K, kg/ha: 20-40-20 kg N-P_2O_5-K_2O/ha vs. 20-40-0 kg N-P_2O_5-K_2O/ha	30-60-30 kg N-P_2O_5-K_2O/ha vs. 30-60-0 kg N-P_2O_5-K_2O/ha	40-80-40 kg N-P_2O_5-K_2O/ha vs. 40-80-0 kg N-P_2O_5-K_2O/ha
Chickpea	205	95	72	24
Urdbean	105	77	20	42
Lentil	90	112	85	73
Pigeonpea	69	163	29	59
Pea	15	148	87	81
Mungbean	14	30	29	-

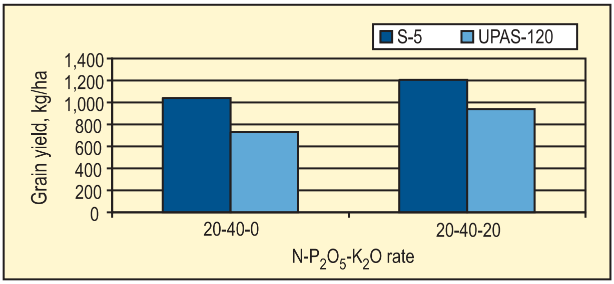


Figure 2. Differential response of pigeonpea genotypes to K application (PRII, 1999).

Generally, improved varieties can be expected to be more responsive to K application due to their larger yield potential and K requirement at critical growth stages. The K response of two genotypes of pigeonpea (*S 5* and *UPAS 120*) was evaluated in 37 AICAR on farm trials. *UPAS 120* showed a 28% yield increase, whereas *S 5* showed a 16% yield increase to 20-40-20 kg N-P_2O_5-K_2O/ha over 20-40 kg N-P_2O_5/ha (**Figure 2**). The magnitude of K responses can increase with irrigation intensity (**Figure 3**) (PRII, 1989), application of other limiting nutrients, method of application, and cropping season.

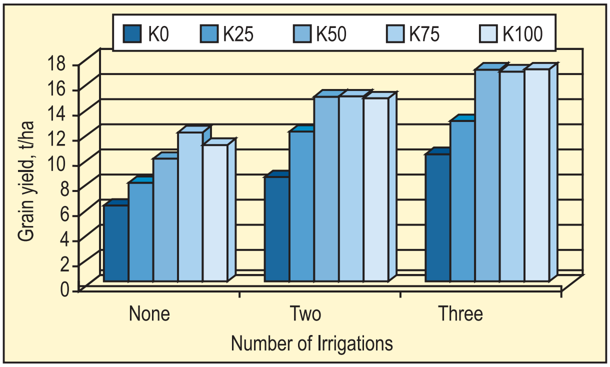


Figure 3. Response of pigeonpea to K application at different levels of irrigation (PRII, 1989).

Potassium nutrition is associated with grain quality, including protein content. Experiments conducted on farmer fields over several rainy and winter seasons under varying rates of K indicated that the protein content of grain improved considerably in all pulse crops studied, as shown in **Figure 4** (Tiwari, 1986).

Added profit is achieved as a result of applying increasing K rates to various pulses (**Table 2**). At 20 kg K_2O/ha, the highest additional return was obtained in pigeonpea, followed by pea, chickpea, lentil, and urdbean (Yadav et al., 1993). Consistently large returns per rupee (Rs) invested in K were obtained at 20 kg K_2O/ha. Added profits obtained from application of either 30 or 40 kg K_2O/ha showed no immediately apparent crop-specific trends. At 30 kg K_2O/ha, pea, chickpea and lentil provided the highest rate of return, and at 40 kg K_2O/ha, pea, pigeonpea and lentil provided added rates of return greater than 2 Rs per Rs invested in K.

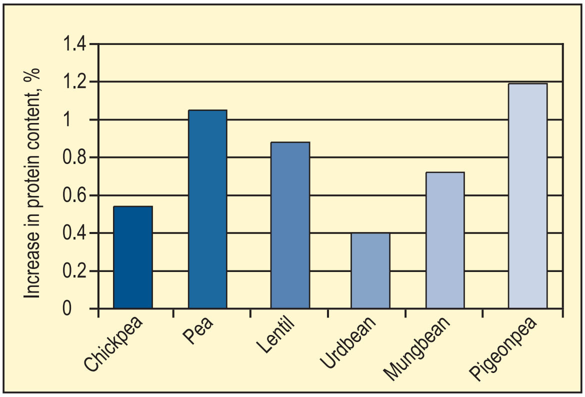


Figure 4. Effect of K application (60 kg K_2O/ha) on protein content of different pulse crops (Tiwari, 1986).

In a separate study, addition of 20 kg K_2O/ha in lentil with recommended N and P rates provided Rs 672/ha (US$14) more return. The study also noted that higher returns due to K application were obtained at higher levels of N and P. For example, application of 40 kg K_2O/ha along with 40-80 kg N-P_2O_5/ha provided an additional net return of Rs 3,600/ha (US$75).

Table 2. Additional profit (Rs/ha) obtained by application of different rates of K (Yadav et al. 1993).

	kg K_2O/ha		
Crops	20	30	40
Chickpea	431 (9.47)[1]	294 (4.30)	39 (0.30)
Urdbean	341 (7.50)	320 (0.46)	119 (1.31)
Lentil	401 (8.82)	273 (4.00)	200 (2.20)
Pigeonpea	770 (17.0)	77 (1.13)	205 (2.25)
Pea	695 (15.3)	367 (5.28)	314 (3.46)

[1]Figures in parentheses indicate the Rs gained per Rs invested in K.

Inclusion of K in nutrient management schedules of pulse crops is not common in many states. However, because of field-level K responses and awareness of soil K depletion under intensive cereal-pulse cropping systems, the importance of K fertilization has recently gained attention. Potassium recommendations based on a soil test and projected yield goal have been made for different pulse crops in several states. As an example, Subba Rao and Srivastava (1999) prescribed recommendations for chickpea (targeted yield of 2 t/ha) on two soil types. Black soils (vertisols) with high clay content and higher available K (1N NH_4OAC, pH 7.0) need K application. By comparison, alluvial soils required K application up to 150 kg extractable K.

Conclusions

Light textured alluvial soils, red and lateritic soils, and shallow black soils need immediate attention regarding K management for enhanced pulse crop productivity. Improved K supply is commonly associated with improved protein content in pulse grains, N fixation, and water use efficiency. Reduced pest and disease infestation as well as improved yield and quality characteristics result when K supply is optimal. **BCI**

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Site-Specific Fertilization Increased Yield and Fruit Size in 'Hass' Avocado

By Samuel Salazar-García and Ignacio Lazcano-Ferrat

In cooperation with an avocado growers association in Nayarit, México, researchers have devised a fertilization strategy capable of sustaining production at high levels which validates the requirement for proper nutrient balance. The strategy is capable of stabilizing the industry and providing competitiveness, two important advantage factors to tree-crop industry members.

The state of Nayarit is the second largest producer of 'Hass' variety avocado in México. Most orchards are located in the hilly regions of Xalisco and Tepic counties. More than 90% are grown under rainfed conditions (1,220 mm mainly distributed from July to October). The volcanic soils planted to avocado have 30 to 80 cm of topsoil and from 2 to 40 m of subsoil. This soil-type has several advantages for growing avocados as its sandy loam texture provides good aeration that enhances root growth. The subsoil can provide both sufficient moisture for tree survival during the dry season as well as excellent drainage during the rainy season, thereby reducing the incidence of avocado root rot (*Phytophthora cinnamomi Rands*).

Recent research in Nayarit showed nutrient removal (kg) for a yield of 20 tonnes (t) of fresh 'Hass' avocado is: nitrogen (N), 51.5; phosphorus (P), 20.6; potassium (K), 93.8; calcium (Ca), 1.7; magnesium (Mg), 5.9; and sulfur (S), 6.9 (Salazar-García and Lazcano-Ferrat, 2001). Although each harvest removes smaller quantities of micronutrients such as iron (Fe), boron (B), and zinc (Zn), deficiencies do occur and have a negative effect on yield, fruit size, and quality of avocados (Salazar-García, 2002).

Commercial mature 'Hass' avocado orchards are primarily fertilized with up to 100 kg N/ha/year and 110 kg P_2O_5/ha/year. Besides being an unbalanced practice, the majority of farmers rarely apply the maximum NP rates indicated. For example, 45 kg P_2O_5/ha more closely represents the average P application rate. After taking into consideration the avocado tree requirements as well as the amount, source, method, and frequency of fertilization, it is foreseen that common farmer management could not produce yields of 20 t or more per year. Insufficient and/or unbalanced fertilization programs are progressively reducing soil fertility, which results in ever declining yields, alternate

bearing, small fruit, and an increase of fruit post-harvest physiological disorders. The combination reduces the competitiveness of Nayarit avocados in both domestic and international markets.

In recognizing the importance of fertilization to increase yield, fruit size, and quality, 'Hass' avocado growers from Tepic and Xalisco counties decided to participate in an avocado nutrition research program. The project was started in 1998 with the goal of increasing grower profitability. At that time, typical yields were 5 to 10 t/ha and commercial-sized fruit (i.e., 'First'–170 to 210 g; 'Extra'–211 to 265 g; and 'Super extra'—more than 266 g) commonly comprised only 20 to 40% of the total yield. The project's initial target was to obtain a 50% increase in both yield and fruit size. This paper reports the results of the first four years of the site-specific fertilization study.

Materials and Methods

An area of 3 ha in a commercial 14 year-old 'Hass' avocado orchard in V. Carranza, Tepic, Nayarit (N 21º 32.04', W 104º 59.08'), at 927 m above sea level was selected as the trial site. The planting arrangement was 156 trees/ha (8 x 8 m) which were grown under rainfed conditions. The orchard received all standard grower management practices, with the exception of fertilization.

Nutrient status was diagnosed for the experimental orchard in 1998 (Salazar-García and Lazcano-Ferrat, 1999) using the indexes of a balanced approach (Kenworthy, 1973). Analysis of foliar nutrient concentrations showed below normal levels for K, S, and B, while N and Zn were in the lower limit of normality.

Soil chemical analyses of the top 30 cm layer were performed at the beginning of the experiment and were used to calculate the nutrient supply capacity of the soil. The test soil had a sandy loam texture, cation exchange capacity (CEC) of 6.7 $cmol_+$/kg, pH 5.8, 8 parts per million (ppm) Bray P-1, 370 ppm exchangeable K, 2.9% organic matter, mid-levels of Mg, sulfate-S (SO_4-S), B, and copper (Cu), low levels of Ca and Fe, and very low levels of manganese (Mn) and Zn.

Nutrient removal by a 30 t target yield was calculated from the data obtained by Salazar-García and Lazcano-Ferrat (2001). An additional amount of nutrients was considered for application based on an estimation of nutrients permanently removed due to annual tree growth (i.e., above and below ground) as well as nutrients removed temporarily by the formation of flowers, fruitlets, and leaves. Probable nutrient losses by leaching, volatilization, fixation, and microbial immobilization were also considered. If no foliar deficiency was detected, maintenance amounts of each nutrient were applied based on soil test results and the expected nutrient removal by the targeted fruit yield.

Table 1. Site-specific fertilization program for a 'Hass' avocado orchard in Tepic, Nayarit.

	Fertilization dosages, kg/tree
Before the beginning of the experiment	
1996	
17-17-17 ($N-P_2O_5-K_2O$)	3.0
1997	
17-17-17 ($N-P_2O_5-K_2O$)	4.0
After the beginning of the experiment	
1998	
Ammonium sulfate (21% N)	3.4
Triple superphosphate (46% P_2O_5)	4.2
Potassium sulfate (50% K_2O)	2.8
1999	
Ammonium sulfate (21% N)	3.4
Triple superphosphate (46% P_2O_5)	4.2
Potassium sulfate (50% K_2O)	2.8
Lime (40% CaO)	1.0
Borax (11% B)	0.2
2000	
Ammonium sulfate (21% N)	8.6
Triple superphosphate (46% P_2O_5)	1.0
Potassium sulfate (50% K_2O)	4.8
Zinc oxisulfate (35.5% Zn)	1.0
Borax (11% B)	0.2
2001	
Ammonium sulfate (21% N)	8.3
Potassium sulfate (50% K_2O)	3.5
Zinc oxisulfate (35.5% Zn)	1.0
Borax (11% B)	0.2

Fertilization dosages were calculated from previous studies (**Table 1**). In 1998, they were applied during the summer months in a 40 cm trench located 2 m around the tree. The prescribed amount of fertilizer was divided in two equal parts for 1998 and 1999. Starting in 2000, three split applications of NPK included: 1/3 N, all the P, and 1/2 K (July), 1/3 N (August), and 1/3 N and 1/2 K (September). Boron and Zn were applied in equal parts in July and September. The annual amount of fertilizer was modified according to changes in nutrient concentration of foliar samples and optimization of the orchard's cost to benefit ratio. Measurements of yield and fruit size were obtained each year and are presented as an average of 80 individual trees randomly selected throughout the orchard.

Results and Discussion

The effect of the fertilization program was first observed three to five months after implementation with re-greening of tree canopies, followed by production of more, but shorter, shoots, less bloom intensity, and delayed winter defoliation.

Fruit yield for the two years previous to the study was considered normal for the region and ranged from 8 to 10 t/ha (**Figure 1**). A sharp increase in yield was observed during the 1999 harvest with average yield reaching more than 32 t/ha. Subsequent years showed the effects of a moderate alternate bearing pattern as yield fluctuated from 25 to 27 t. During the four-year period, avocado yield never dropped below 25 t/ha. These results have had a major impact on growers in the region who cannot recall yield levels near those achieved with this research. The average yield from 1999 to 2002 was 28.4 t/ha, which is quite close to the yield potential of 32.5 t/ha listed for intensively managed irrigated

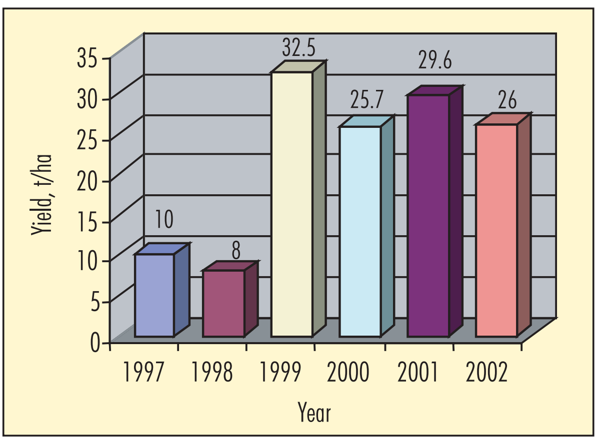

Figure 1. Yield increments as a result of a site-specific fertilization approach (started in summer 1998) in a 'Hass' avocado orchard in Tepic, Nayarit, México.

'Hass' avocado orchards (Wolstenholme, 1986).

Fruit size was increased as a result of site-specific fertilization treatments (**Figure 2**). The proportion of total yield composed by fruit of the largest sizes (170 to >266 g) averaged 27.5% in the two years (1997, 1998) before the beginning of the fertilization trial. In 1999, the proportion of fruit in this size category doubled and showed a constant increase in fruit size over years so that by 2002, 72% of yield corresponded to fruit of premium valued sizes.

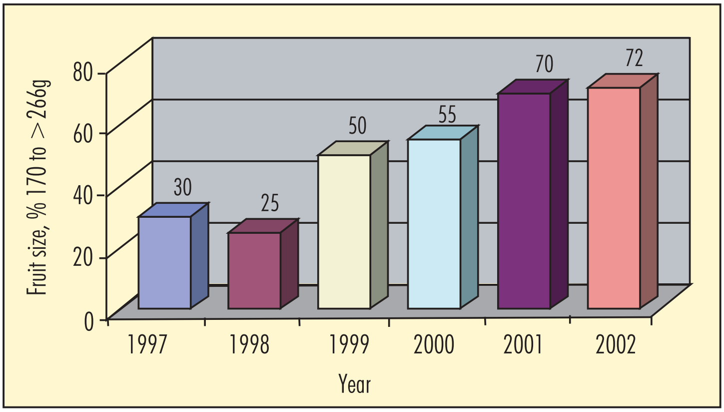

Figure 2. Percentage of fruit of marketable size in a 'Hass' avocado orchard managed with a site-specific fertilization approach (started in summer 1998).

Conclusions

Site-specific fertilization benefited growers by increasing yield and fruit size of the 'Hass' avocado under rainfed tropical conditions (Nayarit, México). Implementation of site-specific nutrient management principles enabled growers of the region to exceed their research goal of doubling avocado yields and fruit size. **BCI**

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Implementation of Best Management Practices in an Oil Palm Rehabilitation Project

By William Griffiths and T.H. Fairhurst

Implementation of best management practices (BMPs), including soil phosphorus (P) recapitalization, resulted in a rapid increase in palm nutrient status and yield in the first year following implementation in South Sumatra. On the highly weathered and low soil P status soils of the region, high yields can only be expected where soil P deficiency has first been corrected by a large one-time application of reactive rock phosphate (RRP).

PT Asiatic Persada (PTAP) is an 8,500 ha oil palm rehabilitation project in Jambi Province, South Sumatra, Indonesia, where the area planted to oil palm exceeds 250,000 ha. Most soils in the plantation are Ultisols with very low soil P and potassium (K) status (**Figure 1**).

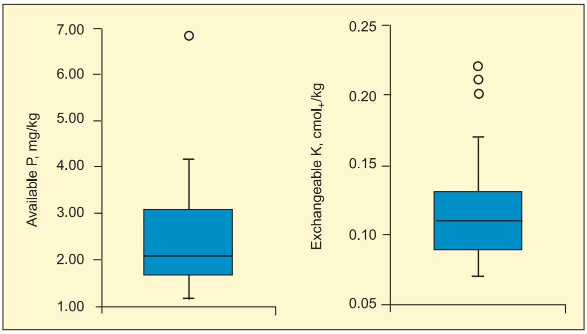

Figure 1. Soil P and K status in PT Asiatic Persada (n=39).

Photo 1.

The topography is typical of Jambi Province with a rolling landscape and moderate to steep slopes intersected with small creeks and rivers. The plantation was planted between 1988-1989 but required extensive rehabilitation when acquired by its present owners in 1999. In some areas, fertilizer had not been applied and palms had not been harvested for several years, and ground cover consisted of mainly hard weeds such as Straits rhododendron (*Melastoma malabathricum*), tropical bracken (*Dicranopteris linearis*), and alang-alang (*Imperata cylindrical*). See **Photo 1**.

In 2001, BMPs were introduced with several objectives. First was to determine the site-specific yield potential under optimal management conditions where yield is limited only by climate and the potential of the planting material. There was a need to demonstrate to plantation staff the required standards of field upkeep and maintenance in line with standards described in the PPI/PPIC oil palm field handbooks (Rankine and Fairhurst, 1999a; Rankine and Fairhurst, 1999b; Rankine and Fairhurst, 1999c). Use of BMPs helped us investigate the effect of a one-time application of RRP to correct soil P deficiency.

Seven representative fields, each about 30 ha and comprising a total of 210 ha, were selected for rehabilitation. Work commenced in

October 2001, in the following step-wise sequence. All woody weed growth was removed and harvest paths and palm circles were established by hand weeding and spraying herbicide (**Photo 2**). Soil conservation measures (platforms, contour paths) were installed to reduce soil erosion losses and surface water run-off (**Photo 3**). Field drains and improved drain outlets were installed in areas affected by temporary and permanent inundation. Supply palms were planted to bring the field to a complete stand of palms. There was a one-time 300 kg P_2O_5/ha application of RRP over the palm inter-rows (**Photo 4**). About 40 t/ha empty fruit bunches (EFB) were applied to improve soil physical properties, supply nutrients, and prevent the loss of applied P fertilizer in surface water run-off (**Photo 5**). Shade tolerant legume cover plants (LCP) (*Calopogonium caerulium*) were established by planting cuttings between each palm (**Photo 6**). Corrective pruning removed unproductive fronds and improved access for harvesting.

Photo 2.

Photo 3.

Photo 4.

Photo 5.

Photo 6.

Except for the ameliorative application of RRP, standard estate fertilizer recommendations were used in the BMP fields: 1.4 kg nitrogen (N)/palm as urea; 0.9 kg P_2O_5/palm as RRP; 1.95 kg K_2O/palm as potassium chloride (KCl); and 0.07 kg magnesium oxide (MgO)/palm as kieserite. Strong interactions were expected between the different procedures. For example, LCP are highly responsive to P fertilizer and thus an application of RRP is expected to increase biological N fixation through increased biomass production in the LCP. Phosphorus fertilizer is comparatively immobile in soil and large losses of surface applied RRP can be expected due to surface wash on sloping land. Thus, an application of EFB mulch not only provides nutrients and a mulch layer, but also helps to reduce losses of surface applied RRP. Installing soil conservation measures, which also facilitate harvesting and crop removal, further reduced losses of fertilizer nutrients.

In some fields, there was a need to fill in large gaps in the palm stand and thus a full return on the rehabilitation effort can only be expected when these supply palms come into production after 24 to 30 months. Nitrogen deficiency symptoms were observed in low lying areas adjacent to creeks and rivers in some BMP fields and field drains were installed to remove standing water and thus improve the availability of soil indigenous N.

Yield. Bunch weight and yield were larger in the BMP fields at the start of BMP implementation. However, on average, yields in BMP fields increased by 6.1 t/ha (58%) in 2002 compared with an average increase of 3.1 t/ha (31%) for all fields in PTAP (**Table 1**). The greater increase in yield in BMP fields was explained by larger increases in bunch number and bunch weight when compared with the estate average. Since there is a time lag of 36 to 40 months between the initiation of a flower and the production of a fruit bunch, the full effect of rehabilitation

Table 1. Mean yield components in BMP fields and PTAP, 2001-2002.

Year	Bunch weight, kg		Bunch production, number/palm		Yield, t/ha	
	BMP fields	Estate average	BMP fields	Estate average	BMP fields	Estate average
2001	13.3	11.6	7	7	10.4	8.9
2002	15.8	13.0	10	8	16.5	12.0
Increase	2.5	1.4	3	1	6.1	3.1
%	19	12	43	14	58	31

cannot be expected until three years after the implementation of BMPs.

Increased yield was explained mainly by the effect of improved nutrient management and better crop care on the number and weight of bunches produced. The oil palm is very sensitive to stress resulting from poor management, drought, and nutrient deficiencies. When crop care is improved, the short-term effect is an increase in bunch weight because a greater assimilate supply allows for improved bunch development. The long-term effect of stress alleviation is to reduce the number of flowers lost due to floral abortion and increase the ratio of female to total flowers (termed the sex ratio) and thus increase the number of flower initiates that result in the production of a harvestable bunch. One field exceeded the estimated attainable yield for PTAP and it is expected that five of the seven BMP fields will reach the attainable yield of 25 t/ha fruit bunches in 2003.

Nutrient status. There was a large improvement in palm nutrient status for N, P, K, and Mg in all BMP blocks in 2002 compared with 2001. There is no evidence of nutrient deficiencies (**Table 2**).

There was a large increase in leaf N, P, and K status from deficiency in 2001 to sufficiency in 2002. To maintain the required palm nutrient status in 2003 and in anticipation of greater yields in 2003, the N fertilizer rate will be adjusted to 1.6 kg N. Since P deficiency has now been corrected, the P application rate will be decreased to 0.3 kg P_2O_5; K rates will be maintained at 1.95 kg K_2O/palm in anticipation of increased yield.

Ground cover. Shade tolerant, N-fixing LCP can be established from cuttings under mature palms. Growth of the LCP was more rapid after the one-time application of RRP and EFB mulch. Since the supply of EFB is limited, PTAP will investigate techniques to establish LCP without empty bunch mulching by increasing the initial supply of NPK fertilizer nutrients to LCP cuttings. An alternative and promising LCP is *Mucuna bracteata*. Seedlings have been grown in a nursery and planted out in the field. These plots and areas planted with *C. caerulium*, but without empty bunch mulching, will be monitored closely to determine whether *M. bracteata* and *C. caerulium* can be established without applying a mulch.

Table 2. Leaf nutrient levels in BMP fields before and after rehabilitation.

Year	Leaf nutrient status (Frond 17), % dry matter				Total leaf bases	As % total leaf bases	
	N	P	K	Mg		K	Mg
2001	2.33	0.130	0.85	0.28	71	30	32
2002	2.67	0.165	1.08	0.30	78	35	32

Pernicious weeds have practically disappeared from BMP fields due to the combined effect of LCP, EFB, and improved soil P status following the remedial application of rock phosphate.

Pruning and canopy management. As the yield increases, it will be important to monitor the palm canopy closely to ensure that sufficient leaves are retained on each tree, but that dead fronds are removed during harvesting and by periodic pruning. Ideally, five spirals of eight leaves or 40 leaves/palm should be maintained on all mature palms. Unproductive palms in the BMP fields will be marked, monitored, and removed to reduce competition with productive palms. Supply palms will require careful maintenance and adequate N, P, and K fertilizer inputs to ensure that they come in to bearing 24 to 30 months after planting.

Economic returns. The average yield increase in BMP blocks in 2002 was +6.0 t/ha FFB [1.32 t crude palm oil (CPO), 0.22% oil extraction rate (OER) at US$480/t], which resulted in an increase in revenue of US$634/ha. This compares with the average yield increase for PTAP of 3 t/ha FFB (0.66 t CPO, 0.22% OER) giving a revenue of US$316/ha (i.e., a net increase in revenue of US$154/ha).

Thus, rehabilitation costs of about US$100/ha were more than offset by the increase in revenue in the first year after rehabilitation.

Discussion and Conclusions

The implementation of BMPs in selected fields in PTAP resulted in a much greater rate of yield recovery. PTAP plans to incorporate the techniques used in BMP fields over about 1,500 ha of the remaining part of the estate. We have shown that the integrated use of RRP, EFB mulch, and shade tolerant cover plants are a cost effective method to rehabilitate low nutrient status soils planted to oil palm. **BCI**

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Sugarcane Response to Soil Phosphorus

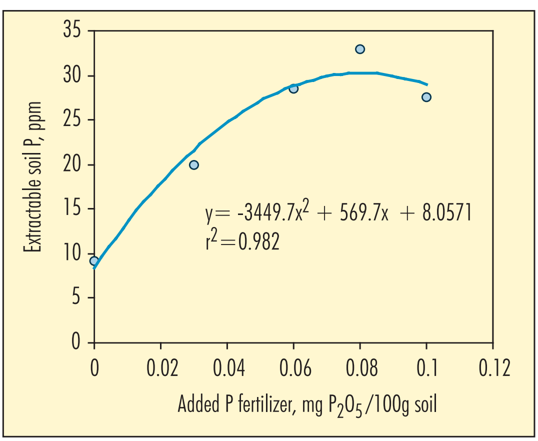
By S.M. Bokhtiar and K. Sakurai

The Bangladesh Sugarcane Research Institute (BSRI) examined the potential for improving cane yield through increased phosphorus (P) fertilizer use accompanied with adequate nitrogen (N), potassium (K), sulfur (S), and zinc (Zn). Results revealed that higher P application rate in a balanced fertilization strategy significantly increased cane and sugar yield. Improved soil P status alone, increased cane yield by 31% over yields obtained under present soil P fertility. A more balanced approach to P nutrition is needed to achieve improved cane and sugar yields.

In Bangladesh, sugarcane is mainly cultivated in the northwestern part of the country and is typically cultivated on an area about 164,000 hectares (ha) annually. Average cane yields for the region are about 41 t/ha. Soils of the region are commonly P deficient with levels far below critical values. Application of P fertilizer promotes root growth, stimulates tillering, influences millable cane growth, and thereby sugarcane yield per ha (Pannu et al., 1985). Besides yield, adequate P nutrition is conducive for higher sugar accumulation in cane tissues. Kumar and Verma (1999) observed that application of 50 kg P_2O_5/ha and above increased cane yield significantly over the control (37.2 to 56.4 t/ha). About 10 to 20% of applied P is utilized, much less than that of other nutrients like N and K (Oseni, 1978).

The objective of the study was to determine the optimum level or range of soil P for sustainable sugarcane production for the High Ganges River Floodplain soils in Bangladesh, represented by the BSRI experimental farm. It is in the Ishurdi series, Typic-Eutrocrept, agro-ecological zone (AEZ) 11; sandy loam; pH 7.5 to 8.0; low in total N, 0.06%, available P 8.0 parts per million (ppm), K 0.19 $cmol_+$/kg, and S 6.0 ppm. The climate of the region is tropical and sub-tropical.

Figure1. Relationship between added P and extractable sodium bicarbonate P in soil after 20 days of incubation.



The six treatments: [T_1, 8 ppm P (control); T_2, 14 ppm P; T_3, 20 ppm P; T_4, 26 ppm P; T_5, 32 ppm P; and T_6, 38 ppm P] were created by adding P fertilizer based on a regression curve (**Figure 1**). Each treatment was replicated three times in a randomized complete block design. One-eyed nursery seedlings (variety Isd 29) grown in polyethylene bags for 40 days were planted in a 8 x 6 m plot with a 1.0 m interrow and 0.45 m interplant spacing. Fertilizer sources for N, P, K, S, and Zn were urea, triple superphosphate (TSP), potassium chloride (KCl), gypsum, and zinc sulfate ($ZnSO_4$). One third of the KCl and the full amount of TSP, gypsum, and $ZnSO_4$ were applied basally and one-third of the N was applied 30 days after seedling transplantation (DAT). The remaining N and KCl were top-dressed at two equal installments at tiller completion (120 DAT) and grand growth stage (180 DAT).

Table 1. Sugarcane yield responses and net profit to soil P levels, BSRI farm, Ishurdi, Bangladesh.

Soil P levels, ppm	Millable cane stalks, '000/ha	Yield, t/ha	Yield increase, t/ha	Gross income (US$/ha)	Variable cost (P fertilizer) (US$/ha)	Net benefit (US$/ha)
T_1- 8	77.5	73.1	—	—	—	—
T_2-14	100.3	84.1	10.7	208	32	175
T_3-20	110.9	91.9	18.5	357	46	312
T_4-26	113.5	94.7	21.3	412	60	352
T_5-32	115.8	97.6	24.2	470	74	396
T_6-38	121.3	115.7	42.3	820	88	733
$LSD_{(0.05)}$	11.3	15.9	—	—	—	—
SE (±)	3.6	5.1	—	—	—	—

N = 198; K = 81; S = 20; Zn = 3 kg/ha, respectively.

Yield and Foliar Nutrient Content as Affected by Varying Soil P Levels

The range of soil P levels significantly increased growth of millable cane stalks and cane yield (**Table 1**). The highest soil P level of 38 ppm produced the highest number of millable cane stalks (121,300/ha) and yield (115.7 t/ha), while control plots which received no P fertilizer produced the lowest number of millable cane stalks (77,500/ha) and yield (73.1 t/ha). The second highest yield of 97.6 t/ha was produced with T_5, which was similar to T_4, T_3, and T_2. Compared to T_1, cane yield increased by 7.9, 13.6, 15.6, 17.8, and 31% using T_2, T_3, T_4, T_5, and T_6, respectively.

S.M. Bokhtiar at sugarcane field, Ishurdi, BSRI farm.

A simple economical analysis for the different soil P treatments was calculated (**Table 1**). There was an excellent response to P application and steadily improved profits with increased P application rate. **Figure 2** shows the significant sugar yield response to increasing levels of soil P and a highest sugar yield of 12.4 t/ha with the 38 ppm soil P level. Because a yield threshold was not reached, further investigation is needed to determine the P and other nutrient requirements to achieve maximum economic yield.

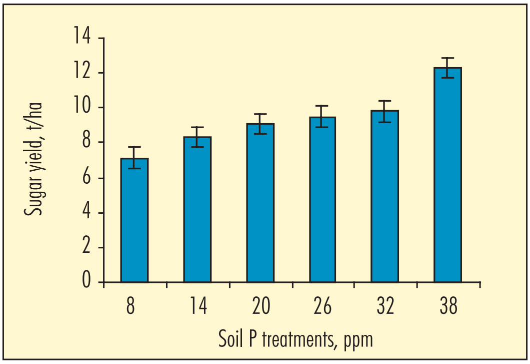


Figure 2. Response of sugar yield to soil P levels. Vertical bars and lines on the vertical bars indicate the mean and standard error of three replicates, respectively.

The range of soil P treatments only improved the concentrations of P, K, and S in leaves, although the response was minimal

(continued on page 25)

Soil Phosphorus Status and Crop Response in Major Cropping Systems of Guangxi

By Tan Hongwei, Zhou Liuqiang, Xie Rulin, and Huang Meifu

A cropping system-specific analysis of past and present phosphorus (P) fertilizer management practices and their impact on current soil P status and crop response to P in Guangxi Province shows that calling for reduced P application rates is clearly unjustified if sustained crop production is truly desired.

Research indicates that P is one of the main plant nutrients limiting crop growth in the subtropical region of southern China. Those soils have inherently low P levels due to intense soil weathering and soil adsorption, as well as a prolonged period of cropping without attention to nutrient balance. Thus, it is especially important to re-examine the soil P status and crop response to applied P fertilizer for high yielding systems in Guangxi.

Fertilization trials and demonstrations are conducted in rice, the major crop in Guangxi Province.

Agricultural Production Systems in Guangxi

The main cropping systems of the lowland soils in Guangxi are rice-rice-winter fallow, rice-rice-vegetable, and rice-rice-green manure. The main cropping systems of the uplands are corn-soybean, corn-sweet potato, peanut-sweet potato, and sugarcane. Rice production in Guangxi is mainly distributed in the central and western regions. The total area of lowland rice is 1.52 million hectares (M ha), of which the rice-rice-fallow cropping system occupies about 1.22 M ha or 80% of the total.

The rice-rice-vegetable cropping system utilizes 0.23 M ha, accounting for 15%, while the rice-rice-green manure cropping system only occupies approximately 0.08 M ha, or 5% of the total (**Table 1**). Upland soils of Guangxi are mainly distributed in the western and central regions. Sugarcane is mainly grown in central and southern Guangxi, while the corn-soybean cropping system predominates in western Guangxi (**Table 2**).

Table 1. Area and distribution of lowland rice in Guangxi.

System	Area, 10,000 ha	Distribution
Early rice-late rice-winter fallow	121.5	Central, West
Early rice-late rice-vegetable	22.8	East, South
Early rice-late rice-green manure	7.6	South, North

Table 2. Area and distribution of major upland cropping systems in Guangxi.

System	Area, 10,000 ha	Distribution
Corn-soybean	31.1	West, Central
Corn-sweet potato	5.2	West, Central
Peanut-sweet potato	21.7	Central, South
Sugarcane	54.9	Central, South

Average fertilizer application rates as well as the N:P:K ratios for rice, corn, sweet potato, soybean, peanut, and sugarcane are explained in **Table 3**. Sugarcane receives the most plant nutrients, followed by corn and rice.

Table 3. Fertilizer application rates (kg/ha) for selected crops in Guangxi.

Crop	N	P_2O_5	K_2O	N: P_2O_5: K_2O
Rice	159.7	62.5	76.2	1: 0.39: 0.48
Corn	169.3	69.0	70.2	1: 0.41: 0.41
Tuber	54.2	43.9	36.6	1: 0.81: 0.68
Soybean	53.1	52.9	47.1	1: 1.00: 0.89
Peanut	53.0	55.3	53.2	1: 1.04: 1.00
Sugarcane	168.5	85.8	115.4	1: 0.51: 0.68

Phosphorus Status of Various Soils and Cropping Systems in Guangxi

Lowland soils. The average total P content of lowland soils ranges between 0.14 and 1.07 g/kg, although the majority of soil P is neither soluble nor plant available. Availability of soil P will vary greatly in lowland systems due to the influence of past fertilizer management and ranges from 0.4 to 22 mg/kg. Results from several years of investigation indicate that average available soil P contents, before the early and late rice seasons, were low, 7.6 and 7.1 mg/kg, respectively. Thus, P is one of the main yield-limiting nutrients for lowland rice. Lowland field trials throughout Guangxi showed that P fertilization can increase available soil P contents from 0.6 to 6.0 mg/kg (**Table 4**).

Table 4. Effect of P application on available soil P in paddy soils, Guangxi.

Site	Available P, mg/kg	
	NK	NPK
Central (Binyang)	5.0	11.0
East (Wuzhou)	5.3	5.9
West (Debao)	2.0	3.5
South (Hepu)	1.1	3.0

Upland soils. Phosphorus status of upland soils was lower than that of lowland soils. Total soil P content for upland soils ranged between 0.17 and 1.0 g/kg, with the range of available soil P being slightly wider than lowland soils (**Table 5**).

Table 5. Typical soil P content in corn-soybean cropping systems, Guangxi.

Crop	Total P, g/kg	Available P, mg/kg	
		Range	Average
Before corn planting	0.17-1.0	0.44-22	6.8
Before soybean planting		0.4-16	4.5

- Examination of 37 corn-soybean cropping system trials found that although average available soil P levels were highest at 6.8 mg/kg, just prior to corn planting, thereafter the system underwent a significant decrease. Thus, after corn harvest, average available soil P levels were lowest at 4.5 mg/kg. The low availability prior to soybean planting jeopardizes the yield opportunity.
- In 107 typical sugarcane growing regions, P content was 0.4 to 20.7 mg/kg with an average of 6.7 mg/kg. Data showed that if stalk yield was high, the uptake of plant nutrients was also high.
- Banana has been traditionally planted in upland soils, although recently plantations have shifted to paddy soils. Nineteen field trials conducted in paddy soils planted to banana had available soil P levels between 1 and 46 mg/kg, averaging about 9.1 mg/kg.
- Pineapple soils had low available soil P, ranging between 0.4 and 13 mg/kg, and had the lowest average of all soils at 2.9 mg/kg with 15 field trials (**Table 6**).

Table 6. Status of soil P content in sugarcane, banana, and pineapple growing regions, Guangxi.

Crop	Total P, g/kg	Available P, mg/kg	Average, mg/kg
Sugarcane	0.16-0.95	0.4-6.7	6.7
Banana	0.15-0.99	0.4-20	4.0
Pineapple	0.11-0.81	0.4-5.7	1.3

Table 7. Effect of P application on rice yield and profit, Guangxi.

Measurement	NK	NPK
Yield, kg/ha	7,220	8,350
Yield increase, kg/ha	—	1,130
Percent yield increase	—	16
Grain yield increase per kg of P_2O_5, kg/ha	—	19
Increased profit, Yuan/ha	—	566

Pineapple is shown with fertilized plots at left and back, and check plot at right front.

Crop Response to Phosphorus Fertilizer

Rice cropping systems. Applying P fertilizer to rice increased yield significantly, averaging about 1,130 kg/ha higher (16%). This improved yield raised profitability by 566 Yuan/ha (US$68/ha). One kg of P_2O_5 was shown to increase rice yield by 19 kg (**Table 7**).

Corn-soybean cropping system. Phosphorus fertilizer increased corn yield between 700 and 1,040 kg/ha. Given the 2.3 mg/kg decrease in available soil P, as measured after harvesting the corn crop, it is apparent that not enough P is being added to compensate for uptake and removal. In fact, P fertilizer application rates ranged only between 38 and 75 kg P_2O_5/ha, which is now proven to be an unsustainable practice for high yield, high quality corn production in southern China. Response of late-planted soybeans to P fertilizer application was more significant than for corn. Phosphorus application increased yield by an average of 340 kg/ha, or 56%. Average increase in profit for the corn-soybean cropping system (**Table 8**) was 1,170 Yuan/ha (US$142/ha).

Sugarcane. Sugarcane yield increased markedly when P was applied at rates between 38 and 75 kg P_2O_5/ha. The average sugarcane yield achieved by applying 38 kg P_2O_5/ha (with adequate N and K) was 4,730 kg/ha (8%) higher than the average yield obtained with N and K application alone. Plots receiving 75 kg P_2O_5/ha produced 12.7 t/ha (20%) more than plots receiving N and K alone. Sugarcane profitability was increased between 947 and 2,530 Yuan/ha or US$115 and US$306/ha (**Table 9**). Past research on maximum economic yield in sugarcane has indicated a potential near 115 t/ha using NPK applications rates of 345-120-450 kg N-P_2O_5-K_2O/ha (Guangxi SFI and PPIC, 1996).

Table 8. Effect of P application on the corn-soybean cropping system, Guangxi.

Measurement	NK	NPK
Corn yield, kg/ha	4,280	4,980
Yield increase, kg/ha	—	700
Percent yield increase	—	16
Soybean yield, kg/ha	610	950
Yield increase, kg/ha	—	340
Percent yield increase	—	56
Inc. profit of corn + soybean, Yuan/ha	—	1,170

Table 9. Effect of P application on sugarcane yield and profit, Guangxi[1].

Measurement	NK	NP_1K	NP_2K
Yield, kg/ha	63,000	67,700	75,700
Yield increase, kg/ha	—	4,730	12,700
Percent yield increase	—	8	20
Inc. profit, Yuan/ha	—	947	2,530

[1] NP_1K=38 kg P_2O_5/ha; NP_2K=75 kg P_2O_5/ha

Conclusions

A wide range of experimental results shows a strong relationship between crop response to P fertilizer additions and available soil P status in a variety of soils. The various cropping systems of Guangxi Province currently are based on soils with low available P contents. Application of P fertilizer to these systems and soils resulted in very significant and profitable yield increases. If P is omitted from common farmer practice, crop yield and profits suffer. These trials point to the continuing need to test higher P application rates as in most cases the response curve for P was linear. Hence, a maximum yield and profitability could not be defined. In such studies it will also be necessary to test the P response curves using higher rates of N, K, and other deficient plant nutrients based on soil test information. While some scientists in China have suggested P application rates could be reduced in certain areas, this does not apply to the vast majority of cropping systems in Guangxi. **BCI**

The authors are staff of the Soil and Fertilizer Institute of the Guangxi Academy of Agricultural Sciences.

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Sugarcane...*continued from page 21)*

(**Table 2**). After harvest, the minor differences in available soil P among treatments indicates the P uptake and use-efficiency is substantially improved when adequate and balanced fertilizers are applied to sugarcane. **BCI**

Table 2. Effect of soil P levels on the nutrient content of sugarcane leaf at mature stage and post harvest soil P level, BSRI farm, Ishurdi, Bangladesh.

Soil P levels,	Leaf, %			Soil P[1],
ppm	P	K	S	ppm
T_1- 8	0.09	1.88	0.09	9
T_2-14	0.09	1.95	0.11	12
T_3-20	0.09	1.95	0.11	13
T_4-26	0.10	1.98	0.11	11
T_5-32	0.11	2.00	0.12	13
T_6-38	0.10	1.88	0.10	11

[1]After harvest

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India's Soil and Crop Need for Potassium

By K.N. Tiwari

The need and importance of potassium (K) for producing crops with high yields and superior quality is greater than ever before. The first stage of implementing a balanced fertilization strategy is using, at the very least, the recommended rates of K along with other needed nutrients. At the same time, steps must be initiated to take a fresh look at the current approach and methodology for making K recommendations. These should primarily address the need for using soil- and crop-specific limits of available soil K. The recommendation system should support above average yields as well as provide progressive farmers with greater income opportunity.

Potassium consumption in India was 1.7 million tonnes (M t) in 2000, about one-seventh of the country's nitrogen (N) consumption. In the entire history of fertilizer use in India, K has been approximately 10% of total NPK usage (**Tables 1 and 2**), although K removal by crops accounts for 16.5 M t or 55% of total NPK uptake and annually exceeds N removal.

Even though India is the world's third largest fertilizer user, the current average rate of nutrient application is 96 kg/ha. This is indicative of only a few well-fertilized areas, whereas the majority of farmland receives very small rates of application. Country statistics show that of all 466 agricultural districts, 65% use less than 100 kg $N+P_2O_5+K_2O$, 28% use between 100 to 200 kg $N+P_2O_5+K_2O$, and 7% use greater than 200 kg $N+P_2O_5+K_2O$. Tapping into this potential market requires an area-wise constraint analysis to determine why fertilizer use patterns are so highly skewed.

Both food and therefore fertilizer needs of India are expected to increase consistently in the decades ahead. The net cropped area has more or less stabilized at 143 M ha. By contrast, India's population—

Table 1. Trends in fertilizer consumption in India.

Year	Consumption, thousand tonnes			
	N	P_2O_5	K_2O	Total
1959-1960	229	54	21	305
1969-1970	1,360	416	210	1,980
1979-1980	3,500	1,110	590	5,120
1989-1990	7,250	2,720	1,070	11,000
1999-2000	11,600	4,800	1,700	18,100

Source: Fertilizer Association of India (FAI) Fertilizer Statistics

Table 2. Trends in fertilizer application in India.

Year	Consumption, kg/ha			
	N	P_2O_5	K_2O	Total
1959-1960	1.5	0.4	0.1	2.0
1969-1970	8.4	2.6	1.3	12.3
1979-1980	20.6	6.8	3.6	31.0
1989-1990	40.5	16.5	6.4	63.4
1999-2000	61.3	25.4	9.0	95.7

Source: FAI Fertilizer Statistics

now over 1 billion—is expected to grow by 14 to 15 million each year. Each hectare of net sown area, which currently supports more than seven persons, will need to become more productive in the future.

India's highest policy-making body has projected annual food grain requirement at 337 M t by 2011/12 (**Table 3**). Agricultural policies, in spite of their aberrations and inconsistencies, have always depended on planning for adequate and sometimes exaggerated amounts of fertilizer to meet agricultural production targets. Currently, available estimates are for 30 M t of N+P_2O_5+K_2O by 2006/07 and 45.5 M t by 2011/12. If one examines the past trends in growth of fertilizer consumption, it becomes apparent that these targets will require massive efforts in production, importation, distribution, and application to become a reality. Fertilizer consumption increased by 3.1 M t during the decade of the 1970s, by 5.9 M t during the decade of the 1980s, and by 7.1 M t during the decade of the 1990s. The Planning Commission target of 45 M t translates into 2.5 times present levels of consumption. Will fertilizer use increase by 27 M t in the next 12 years?

Table 3. Some projections on agricultural production and fertilizer consumption in India.

Commodity	1999-2000, M t	2011-2012 Target, M t
Rice	86.0	128
Wheat	70.8	130
Coarse grains	31.4	48.9
Pulses	14.8	29.8
Total food grains	203	336.7
Oilseeds	25.2	58.9
Sugarcane	296	680
Fertilizer consumption, N+P_2O_5+K_2O	18.1	45.5

Source: Fertiliser Statistics (FAI) and Planning Commission of India.

The Fate of Balance

Balanced fertilizer use at the macro level in India is equated with the N:P_2O_5:K_2O consumption ratio of 4:2:1—a nominal requirement for grain-based agricultural systems whose crop residues are returned to the field. This ratio has been accepted for almost half a century, but is considered outdated by many scientists.

Table 4 ranks the major agricultural states of India in order of

Table 4. Ranking of Indian states according to degree of N:K_2O imbalance at two N:K_2O ratios (departure from 4:1and 2:1 ratio).

State	K_2O consumption taking N=100[1]	Departure from 25 taking N=100 (4:1)	Departure from 50 taking N=100 (2:1)
Haryana	0.7	-24.3	-49.3
Rajasthan	1.1	-23.9	-48.9
Punjab	2.1	-22.9	-47.9
Jammu & Kashmir	2.8	-22.2	-47.2
Uttar Pradesh[2]	4.1	-20.9	-45.9
Madhya Pradesh[2]	7.0	-18.0	-43.0
Bihar[2]	8.8	-16.2	-41.2
Gujarat	9.7	-15.3	-40.3
Andhra Pradesh	13.6	-11.4	-36.4
Himachal Pradesh	14.5	-10.5	-35.5
Maharashtra	19.2	-5.8	-30.8
Orissa	21.2	-3.8	-28.8
Karnataka	30.4	5.4	-19.6
West Bengal	35.1	10.1	-14.9
Assam	36.2	11.2	-13.8
Tamil Nadu	46.1	21.1	-3.9
Kerala	82.5	57.5	32.5
North Zone	3.1	-21.9	-46.9
West Zone	10.8	-14.2	-39.2
East Zone	21.2	-3.8	-28.8
South Zone	27.4	2.4	-22.6
All India	12.9	-12.1	-37.1

[1] Average of three years 1997-2000, [2] State before division. Data source: FAI Fertilizer Statistics

Table 5. Nitrogen and K response ratio (kg/kg) of crops in long-term fertilizer experiments: 1973-77 vs. 1992-96.

Location (Soil) and cropping system	Nitrogen 1973-77	Nitrogen 1992-96	Potassium 1973-77	Potassium 1992-96
Palampur (Alfisol)				
Maize	14.6	-1.6	2.4	20.0
Wheat	4.3	-3.1	3.6	13.2
Ranchi (Alfisol)				
Soybean	-10.4	-8.1	4.1	20.6
Wheat	-7.8	-1.4	1.0	15.9
Coimbatore (Inceptisol)				
Fingermillet	3.1	5.4	-11.4	13.4
Maize	1.7	-1.3	-1.3	14.5
Bhubaneswar (Inceptisol)				
Rice (kharif)	6.7	2.6	6.9	8.2
Rice (rabi)	11.2	3.2	2.7	5.5
Jabalpur (Vertisol)				
Soybean	26.0	8.4	2.9	13.7
Wheat	7.0	0.5	8.4	6.0

Source: Swarup, A. and Srinivasa Rao Ch. (1999) Fert. News 44(4): pp 27-30, 33-40 & 43.

departure from the traditional 4:1, and for a more contemporary comparison 2:1 ($N:K_2O$) ratios. That is, the degree of imbalance with respect to K. All major states except five have a ratio wider than 4:1. However, all states have ratios wider than 2:1. Among geographical zones, $N:K_2O$ ratios are relatively greater in the north and west zones as compared to the south and east. That unbalanced plant nutrient application is widespread in India is apparent from this data, but throughout the intensively cultivated, irrigated Indo-Gangetic plains, which contributes a large share of the total food grain production.

Concern for Soil Nutrient Depletion

The major reason for soil nutrient depletion is unbalanced fertilizer application—large N applications without matching amounts of other nutrients, particularly K. Farmers in many areas are, in effect, using N fertilizer as a 'shovel' to mine soil reserves of other nutrients, particularly K, P, and sulfur (S), and in several cases micronutrients as well. It is the depletion of nutrients that has resulted in progressively larger increases in crop response to K with the passage of time (**Table 5**).

Mining of India's soil K reserves continues at an alarming pace. One of the greatest obstacles is the continuation of a pre-1960s mindset that most Indian soils are well supplied with K and thus do not need K application. It is often forgotten that soil K levels which support crop yields of 1 to 2 t/ha may not be capable of supplying a 5 to 7 t/ha crop yield. The alarming situation is that in many cases, even the recommended rates of fertilizer application result in soil nutrient depletion because they turn out to be sub-optimal for supporting the high-yielding, intensive cropping systems that will be required in the future (**Table 6**).

Table 6. Sub-optimal status of official state recommendation for NPK application rates (example: wheat).

Location	Mean grain yield (1971-87), kg/ha: State NPK rec.	1.5 x State rec,	Extra yield, %
Barrackpore	2,300	2,900	+26
Delhi	4,300	4,700	+9
Jabalpur	3,800	4,200	+11
Palampur	2,600	3,100	+19
Pantnagar	3,900	4,500	+15

Source: Nambiar, KKM (1994) ICAR-AICRP-Long Term Fertilizer Experiments.

The state of Punjab, which has one of the widest $N:K_2O$ ratios, estimated K removal by the crop is 709,000 t or 38 times the amount of K_2O applied through fertilizer. In fact, K removal in Ludhiana district alone is seven times the entire state's consumption. Looked at in different ways,

Table 7. Distribution of projected fertilizer consumption in India among N, P, and K, according to three ratios of $N:P_2O_5:K_2O$ consumption.

Nutrient	2006/07, M t 6.8:2.8:1 (current pattern)	2006/07, M t 4:2:1	2006/07, M t 2:1:1	2011/12, M t 6.8:2.8:1 (current pattern)	2011/12, M t 4:2:1	2011/12, M t 2:1:1
N	19.2	17.1	15.0	28.9	25.7	22.5
P_2O_5	7.9	8.6	7.5	11.9	12.9	11.2
K_2O	2.8	4.3	7.5	4.2	6.4	11.2
Total	30.0	30.0	30.0	45.0	45.0	45.0

K removal is 1.4 times N removal, and K addition is less than 2% of N applied. Punjab soils show an annual depletion of 100 kg K_2O/ha, an alarming situation for the country's most intensively cropped state and leading food grain producer. Punjab unfortunately mirrors the situation in much of the Indo-Gangetic belt, including Haryana, Uttar Pradesh, and Bihar.

Soil nutrient depletion may not be as critical in the short term, but in the medium to long term it has grave implications...(i) more acute and multiple plant nutrient deficiencies, (ii) reduced fertilizer use efficiency and returns from fertilizer application, (iii) weakened foundation for high-yielding sustainable farming, and (iv) very high remedial costs for rebuilding depleted soils.

Opportunities and Strategies

While the projection for large increases in fertilizer use offers equally large opportunities, the "hidden" challenge lies in changing the ratio in which plant nutrients must be used. Scientific knowledge tells us that crop output from an unbalanced 45 M t of nutrient use (2011/12 projection) can be obtained with smaller tonnage, but with better balance among $N:P_2O_5:K_2O$. Serious initiatives must be implemented to break the psychological barrier of 4:1 as the ideal $N:K_2O$ ratio in the Indian mindset, particularly among central and state government personnel. This will not be easy as consumption has not even reached the 4:1 ratio and further fertilizer projections are not aimed at narrowing this ratio. At 30 M t $N+P_2O_5+K_2O$ in 2006/07 and 45 M t in 2011/12, three different patterns of N, P, and K use are based on: (i) the current consumption pattern of 6.8:2.8:1, (ii) the traditional 4:2:1 ratio, and (iii) a more progressive 2:1:1 ratio (**Table 7**).

Using 2006/07 as an example, the distribution of 30 M t nutrient in a 4:2:1 ratio will save the farmers and the country US$300 million annually when compared to continuing with the currently prevalent wide ratio of 6.8:2.8:1, simply by substituting a part of the costlier N with less expensive K_2O while narrowing the nutrient ratio. The benefits of narrowing the plant nutrient ratios are thus agronomic, economic, and ecologically sound because of higher N-use efficiency. Appropriate initiatives are needed quickly and on a large-scale if the goal of balanced plant nutrient application is to be achieved for India. **BCI**

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Dr. Sam Portch Honored with Friendship Award in China

Dr. Sam Portch, PPIC Vice President (retired), PPI/PPIC China and India Programs, recently received the prestigious "Friendship Award" which recognizes foreign experts who have made outstanding contributions to economic construction and social development in the People's Republic of China (PRC). The State Administration of Foreign Experts Affairs (SAFEA), authorized by the State Council of the PRC, first established the Award in 1991. The annual presentation ceremony in Beijing took place before China's National Day, October 1. Dr. Portch was one of only 51 individuals receiving the Award in 2002, representing 17 countries. An estimated 440,000 foreigners are working in China.

Dr. Sam Portch, at left, accepts the Friendship Award from Mr. Qian Qichen, Vice Premier of the State Council, PRC, during the ceremony in Beijing.

The Award was presented by Mr. Qian Qichen, Vice Premier of the State Council, on the occasion of the 53rd anniversary of the founding of the PRC. Mr. Zhu Rongji, Premier, also congratulated the recipients. The leaders commended the foreign experts for their contributions to China's social development and economic, scientific, technological, educational, and cultural construction. Mr. Qian stated that with a population of 1.3 billion, China's stability and prosperity is of great significance to the civilization, peace, and development of the whole world.

Dr. Portch is a well-respected leader, working in international agriculture for more than 35 years with government agencies and the private sector. He joined PPI/PPIC in 1988 and directed the agronomic research and education programs of the Institute in China since 1989. Based in Hong Kong, he traveled to all regions of China.

In accepting the award, Dr. Portch acknowledged the PPI/PPIC China Program staff, PPI/PPIC offices in North America, companies and government agencies who support the Institute's programs, the Chinese Academy of Agricultural Sciences, the Ministry of Agriculture, and cooperation of provincial institutions, extension personnel, farmers, and others who have helped achieve more balanced fertilization programs.

"I accept this honor on behalf of all who have cooperated for the progress of agriculture in China. It is this group of many that won the award," Dr. Portch said. **BCI**

Dr. Jin to Direct PPI/PPIC China Program Following Retirement of Dr. Sam Portch

Dr. Sam Portch has retired from his responsibility as PPIC Vice President, China and India Programs. Dr. Ji-yun Jin, who served as Deputy Director of the China Program (based in Beijing) since 1990, was appointed Director in late 2002 and will continue to coordinate the agronomic research and education efforts of other staff in China.

Dr. Portch

Dr. David Dibb, PPI President, acknowledged numerous major accomplishments related to the work of Dr. Portch and his staff. "We are truly proud to be a part of the tremendous achievements in agronomic understanding in China. Sam Portch has a rare talent for building bridges of cooperation. He brought a sense of dedication to progress through knowledge during his tenure with the Institute."

A native of Ontario, Canada, Dr. Portch earned his B.Sc. and M.Sc. degrees from McGill University in Montreal and his Ph.D. at the University of Arkansas. During his long career in international agriculture, Dr. Portch had experience in more than 35 countries. He and his wife, Dorothy, have moved from Hong Kong and plan to spend part of their time in Ontario, while also visiting other parts of the world.

Dr. Jin

Dr. Jin was born in Henan Province of China and received his B.S. degree from Jilin Agricultural University in 1977. After earning his M.S. at the Chinese Academy of Agricultural Sciences (CAAS), he continued his studies at Virginia Tech and completed his Ph.D. in 1985. His research work on potassium (K) with soils of northern China found significant yield responses and helped change the traditional belief that many of the soils did not need K.

His leadership in fertilization studies, soil testing, and balanced fertilization practices are well known and widely respected. He has been a council member of the Soil Science Society of China and the Chinese Society of Plant Nutrition and Fertilizer Sciences for several years, and has been honored for many professional achievements.

"We are fortunate to have a scientist of Dr. Jin's stature to continue in a leadership role with the PPI/PPIC China Program. Many opportunities still exist and we are confident of continued success in agronomic programs there," Dr. Dibb emphasized. **BCI**

A Systematic Approach to Soil Fertility Evaluation and Improvement, a new publication authored by Dr. Sam Portch and Dr. Arvel Hunter, is now available. For more information, contact the PPI/PPIC China Program office in Beijing (e-mail: jyjin@ppi-ppic.org) or the PPI/PPIC International Program office in Saskatoon, SK, Canada (e-mail: ppic@ppi-ppic.org; phone 306-652-3535).

It's a Black and White Issue

I am writing this immediately following the IFA-FAO Agriculture Conference, *Global Food Security and the Role of Sustainable Fertilization*, held in Rome, Italy, in March, 2003. The experts selected to address a wide range of scientific and policy issues that constrain…or may improve…fertilizer use, clearly made the point that **fertilizers are essential to food security**. It's as clear cut, *as black and white an issue*, as that.

I hope you are asking yourself: "If it is so clear cut, why then are so many still suffering from insufficient food or inadequate diets?" As clear as the fertilizer/food security issue is, the means for achieving it is much less obvious. I think the Conference made great strides in helping resolve thinking and thereby the opportunity for progress by elucidating:

- Transforming research into knowledge about soils and fertilizer management as well as providing technologies appropriate for the education and economic status of recipient farmers.
- Sustainable development of food production systems is reliant upon maximum productivity.
- Use of existing knowledge is often constrained by either lack of or misguided political will…and policy to make it happen.

If policy is indeed the bottleneck to food security, it was pointed out that we too often pick the wrong issues or policy to attack. A part of what I heard was that: *It isn't* policies to subsidize agriculture in developed countries that retard developing country agriculture. *It is* policies and decisions to exclude new and helpful technologies (such as genetically modified crops). *It isn't* a one-size-fits-all approach to food production that works. *It is* the expectation of industry investment before reasonable economic stability exists. *It is* the lack of financial structures and physical infrastructure that constrains and retards progress.

Although there are competing interests for support, the Conference made a bold and hopefully effective attempt in building common understanding—and the underpinning perspective—that 'it' will only happen through partnership. The readers of *Better Crops International* are instruments in resolving food security, mostly as researchers and educators. I challenge you to learn the real issues, avoid politically correct solutions. You are part of the solution for resolving the chronic state of world food insecurity. You know *it's as black and white an issue as this:* **Fertilizers are essential for food security**. Partnerships and progressive policies aimed at securing a sustainable food supply are needed. It's as clear cut, *as black and white an issue*, as that.

Mark D. Stauffer
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and President, PPIC

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