

# Better Crops

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# International



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Cerrado: A Success  
Story in Soil  
Management**

**Precision Nutrient  
Management in  
Intensive Irrigated  
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**Phosphorus  
Residual Effect in  
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with Potatoes**

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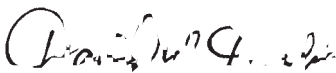
# To Our Better Crops (BC)/ Better Crops International (BCI) Readers...

*This issue represents the re-introduction of BCI as a stand-alone publication. As many of you know, the Institute published BCI separate from BC during the period of 1985-1994, a total of 19 issues. At the time we discontinued publication of BCI in 1994, we felt that by combining it with BC, we could improve production efficiency, including a cost savings.*

*However, its absence has convinced us that we need to have a publication to convey the growing wealth of international crop production information to you, our readers. Further, PPI's involvement in the world's market place...and our growing international staff...dictates that we give more attention to that segment of agronomic information.*

*Initially, BCI will be published twice each year, one issue at mid-year, another toward year's end, with a minimum of 16 pages per issue.*

*We wish to express our gratitude to the Government of Saskatchewan, Canada, for providing some of the monetary support which allows us to publish BCI.*



*David W. Dibb, President  
Potash & Phosphate Institute*

# Phosphorus Status of Soils in India

By R. Hasan

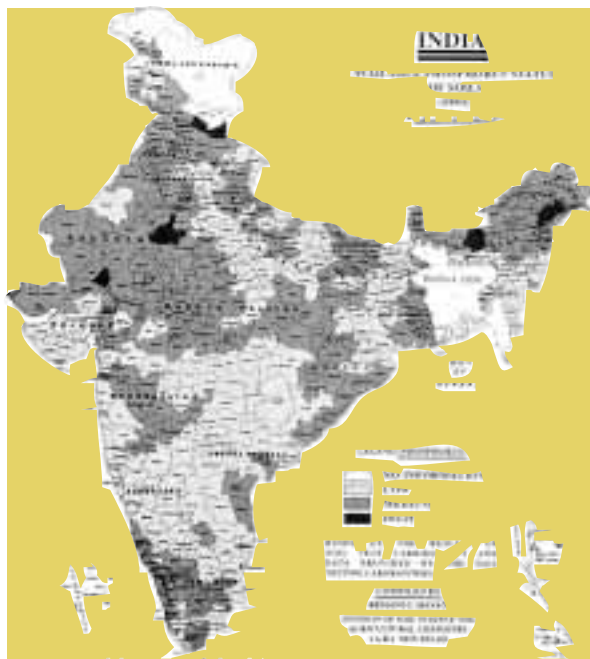
*Phosphorus (P) is one of the three major nutrients required in crop nutrition, the other two being nitrogen (N) and potassium (K). Phosphorus plays many vital roles in crop growth and is referred to by many as the “king-pin” in Indian agriculture.*

Information on P fertility status of soils is of great importance, since it helps determine the level of P fertilizer to be applied to crops. The information is equally useful for P fertilizer distribution and planning at both macro and micro levels.

The P fertility status of soils in India was first compiled in 1979. A new map based on about 9.6 million soil test summaries was published in 1993 and is shown in Figure 1.

For available P in Indian soils, 49.3 percent of the districts are in the low category, 48.8 percent are medium and 1.9 percent in the high P category. Compared to an earlier summary,

Figure 1. Available P status of soils in India.



the low fertility class has increased by 3 percent, while the medium and high categories have decreased by 2.7 and 0.3 percent, respectively. The distribution of districts into fertility classes based on available P status in soils is shown in Table 1.

An appraisal of available P status in relation to the major soil groups or associations indicates that generally the deep black, grey brown, desert and red loamy soils of semi-arid regions have medium fertility level. Similarly, foothill soils, alluvial strips of the northern region, and coastal alluvium that are not sandy in nature largely depict medium available P status. The few districts in which the soils are rich in this nutrient are usually comprised of arid tracts, foothills of high altitude, and cold and semi-dry regions where the intensity of cultivation has been low. The vast alluvial tracts of central, eastern and southern parts of the country, the latosols,

**Table 1.** Distribution of districts and Union territories into fertility classes according to the status of available P in soil.

State/Union territory	No. of districts for which soil tests obtained	Fertility classes		
		Low	Medium	High
Andhra Pradesh	21	17	4	–
Arunachal Pradesh	5	–	5	–
Assam	9	1	6	2
Bihar	26	12	14	–
Chandigarh	1	1	–	–
Dadar & Nagar Haveli	1	–	1	–
Delhi	1	1	–	–
Goa	1	1	–	–
Gujarat	19	14	5	–
Haryana	11	2	9	–
Himachal Pradesh	11	2	7	2
Jammu & Kashmir	10	1	9	–
Karnataka	19	16	3	–
Kerala	10	3	7	–
Madhya Pradesh	45	15	30	–
Maharashtra	25	17	8	–
Manipur	1	1	–	–
Meghalaya	2	2	–	–
Mizoram	1	1	–	–
Nagaland	6	6	–	–
Orissa	13	5	8	–
Pondicherry	1	1	–	–
Punjab	12	2	10	–
Rajasthan	26	2	21	3
Tamil Nadu	13	8	5	–
Uttar Pradesh	55	41	14	–
West Bengal	15	4	11	–
Tripura	3	3	–	–
<b>Total</b>	<b>363</b>	<b>179</b>	<b>177</b>	<b>7</b>
<b>Percent of total</b>	<b>–</b>	<b>49.3</b>	<b>48.8</b>	<b>1.9</b>

medium black, mixed red and black soils, red (gravelly) loams of semi-humid or humid regions and sandy coastal alluvium are usually low in available P.

The information is of direct use for deciding application of P fertilizer. Phosphorus fertilizer is needed in soils testing both medium and low in P status. Accordingly, about 98 percent of the districts in India need fertilizer P application. Higher levels of fertilizer P are required in soils testing low. Likewise, fertilizer P to be applied can be reduced when soils test high in available P. About 50 percent of the districts in India need higher levels of P fertilizer than are currently being used. **BCI**

*Dr. Hasan is Principal Scientist at Division of Soil Science and Agricultural Chemistry, Indian Agricultural Research Institute, New Delhi-110 012, India.*

# Phosphorus Residual Effect in Andisols Cultivated with Potatoes

By Juan Córdova, Franklin Valverde and José Espinosa

*Soils derived from volcanic ash (Andisols) cover an appreciable area of Central and South America. The clay fraction of Andisols is dominated by allophane and imogolite (amorphous, short range ordered minerals) which come from the weathering of pyroclastic material produced from recent volcanic depositions. Research conducted in the last 20 years has demonstrated that humus-aluminum (Al) complexes also play a significant role in Andisol chemical behavior.*

One of the most important characteristics of Andisols is their high capacity to immobilize (fix) phosphorus (P) on the surface of the amorphous minerals. This is perhaps the principal chemical constraint of Andisols. It seems that the P fixing capacity varies with the type of clay mineral, affecting the residual value of phosphate applications.

## Phosphorus Fixation Mechanisms in Andisols

Initially, P fixation in Andisols was considered to occur only on the active surface of allophane and imogolite. Fixation mechanisms include chemisorption and displacement of structural silicon (Si). The importance of Al complexes in the P fixation processes has attracted attention. Soil humus in Andisols readily forms metal complexes with transition metals like Al. Furthermore, hydroxyl groups attached to the complexed Al enter into ligand exchange reactions with phosphates ( $\text{HPO}_4$  and  $\text{H}_2\text{PO}_4$ ).

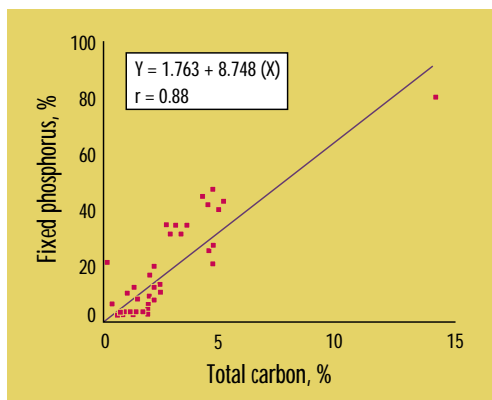
Formation of allophane and imogolite is restricted by the accumulation of humus and the

subsequent formation of humus-Al complexes. The strong complexation of Al with humus limits the possibility of coprecipitation of Al and Si released from the weathering of volcanic ash. This process is common in Andisols of high altitude. Accumulation of organic matter is higher in volcanic soils located at higher altitude (more than 2,000 m above sea level).

Indirect evidence obtained in Andisols of Ecuador and Colombia leads to the conclusion that P fixation is strongly related to the carbon (C) content of the soil (humus-Al complexes). This would indirectly indicate the pattern of clay mineral formation in the soil and the intensity of P fixation. It seems that soils dominated by humus-Al complexes tend to fix more P. From the practical point of view, it seems that in

Andisols, total C content would be a sensitive parameter to predict P fixing potential of the soil. Figure 1 illustrates the good correlation found between P fixed and total C content of 42 Andisols from Ecuador.

Figure 1. Correlation between total carbon and P fixation in Andisols of Ecuador.



## Residual Phosphorus in Andisols Cultivated with Potatoes

It has been reported from several parts of the world that calibration studies on Andisols to relate soil extractable P with crop yield and fertilizer requirements do not work well for all crops. This is the case of potatoes grown in soils derived from volcanic ash in the highlands of Ecuador. To test this condition, potato field experiments were conducted at two locations, El Chaupi and Santa Teresita. Soil at the test areas is Melanudand, typical of the potato country in the highlands of Ecuador.

At El Chaupi, potatoes were grown in the same plots for three consecutive growing cycles. Results of the experiment presented in Table 1 indicate that yields obtained in the check plot are low even though the P content, extracted with Olsen solution, was high at 28 parts per million (ppm). The general P critical level for this soil is 12 ppm. There was an appreciable yield response to increasing P rates in all the growing cycles, indicating that the P residual effect in this soil is low, but the soil test did not reflect this fact. The soil P test in the plot which received an application of 300 and 450 kg P<sub>2</sub>O<sub>5</sub>/ha in the first and second cycle increased to 38 and 59 ppm, respectively. However, potato yields in the third cycle, in the same plots but without P application, were low again. The same trend was observed with low



and high application rates. The photo taken at flowering in the third cycle illustrates the differences among a plot which had 300 kg P<sub>2</sub>O<sub>5</sub>/ha during the first and second cycle and none in the third (foreground plot), the check plot (middle plot) and a plot with 300 kg P<sub>2</sub>O<sub>5</sub>/ha in the third cycle (back plot).

Data presented in Table 2



*Potato crop at flowering in the third cycle at El Chaupi site. Foreground plot received 300 kg P<sub>2</sub>O<sub>5</sub>/ha during the first and second cycle and none in the third. Middle plot is check plot. Back plot received 300 kg P<sub>2</sub>O<sub>5</sub>/ha in the third cycle.*

*Effect of phosphate application on potato plant growth at the Santa Teresita site.*

**Table 1.** Residual P effect on potato yield and its relation to soil test at El Chaupi site.

Cycle 1		Cycle 2		Cycle 3		Soil P test <sup>1</sup> ppm
P <sub>2</sub> O <sub>5</sub> kg/ha	Yield t/ha	P <sub>2</sub> O <sub>5</sub> kg/ha	Yield t/ha	P <sub>2</sub> O <sub>5</sub> kg/ha	Yield t/ha	
0	3.09	0	6.04	0	6.37	28
		0	5.09	300	32.39	41
		300	39.34	300	31.19	46
150	18.46	0	9.90	0	8.33	28
		150	32.65	0	11.32	32
		150	35.44	150	30.45	40
300	27.60	0	17.72	0	7.90	27
		300	36.54	0	12.44	38
		300	39.86	300	32.63	64
450	27.74	0	18.84	0	13.21	34
		450	42.55	0	24.09	59
		450	45.12	450	28.28	89

<sup>1</sup>Soil P test after the third cycle; P extracted with NaHCO<sub>3</sub> + NH<sub>4</sub>F + EDTA (Olsen)

**Table 2.** Potato yield in the third cycle related to previous phosphate applications at El Chaupi site.

Cycle 1	Cycle 2	Cycle 3	Total P <sub>2</sub> O <sub>5</sub> applied	Yield, t/ha
P <sub>2</sub> O <sub>5</sub> rate, kg/ha				
0	0	300	300	32.39
150	150	0	300	11.32
300	0	0	300	7.90
150	150	150	450	30.45
450	0	0	450	13.21
0	300	300	600	31.20
300	300	0	600	13.43
300	300	300	900	32.63
450	450	0	900	24.08

**Table 3.** Effect of phosphate application on potato yield at the Santa Teresita site.

P <sub>2</sub> O <sub>5</sub> rate, kg/ha	Yield, t/ha
0	5.52
150	30.61
300	33.57
450	35.50

suggest that even at very high rates of phosphate application, the fixing capacity of the soils is not satisfied, and the residual benefit is low. To obtain an adequate potato yield, P application is needed every cycle. The data reported from the Santa Teresita site cover only the first cycle but illustrate equally the high fixing capacity of these soils (Table 3 and photos).

### Conclusion

Phosphate fixation potential of Andisols appears to be related to the presence of different materials in the clay fraction as a result of different weathering conditions of volcanic ash. Soil dominated by humus-Al complexes seem to have higher P fixing potential, which is apparently difficult to satisfy. Nutrition management of potato in these type of soils requires a high P application every cycle due to the low P residual effect. **BCI**

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## Robert E. Wagner Award Nominations Due



The Robert E. Wagner Award was established in 1988 by the PPI Board of Directors to recognize distinguished contributions to advanced crop yields through maximum yield research (MYR) and maximum economic yield (MEY) management. The MEY concept, also known as most efficient yield, can provide a solid foundation for better meeting world food needs.

The Award honors Dr. Wagner, retired President of PPI, for his many contributions to agriculture. He is widely recognized for originating the MEY management concept...for more profitable, efficient agriculture.

Last year's recipient in the senior scientist category was Dr. L.D. Bailey of Agriculture and Agri-Food Canada's Brandon Research Centre and in the young scientist division Mr. David Quipeng Zeng, Soil and Fertilizer Institute of the Guangdong Academy of Agricultural Sciences, People's Republic of China. The recipient in each category receives a \$5,000 monetary award.

The format for preparation of nominations for this Award can be obtained by contacting the Potash & Phosphate Institute, 655 Engineering Drive, Suite 110, Norcross, Georgia 30092-2837; phone (770) 447-0335, ext. 203, fax (770) 448-0439. Private or public sector agronomists, crop scientists and soil scientists from all countries are eligible. Nominations must be received by December 31, 1996. **BCI**



# Soils under Cerrado: A Success Story in Soil Management

By A. Scheid Lopes

*Until the 1970s, the cerrado region of Brazil was considered marginal for crop production. However, the technologies developed by scientists of the Cerrado Research Center and other research institutions have completely changed the picture. The objective of this article is to present a summary of management technologies, already practiced by a great number of farmers, which remove low inherited soil fertility as a limiting factor for crop production. The goal is to achieve maximum economic yields (MEY) in a sustainable way in a period of 3 to 4 years.*

The area under cerrado (savanna) vegetation in central Brazil occupies 2.04 million square km or 23 percent of the country. It is estimated that 50 percent of this area is arable land and two-thirds could be incorporated into agriculture/livestock/forestry production. Annual rainfall ranges from 900 to 2,000 mm, usually in the 1,000 to 1,400 mm range. The mean annual temperature is 22°C in the south of the region and 27°C in the north (Goedert, 1989). Most of the soils in this area are highly weathered Oxisols (46 percent), Ultisols (15 percent) and Entisols (15 percent), with serious limitations for crop production in terms of low natural soil fertility.

These soils are acid and have low availability of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), molybdenum (Mo) and zinc (Zn). They are high in aluminum (Al) saturation and possess high P fixation capacities.

Besides these chemical problems there are other production limitations (Lopes and Guilherme, 1994):

- typically a 5 to 6 month dry season (April to September);
- dry spells of one to three weeks, locally called "veranicos", during the rainy season, generally associated with high evapotranspiration rates;
- low water holding capacity, even in clayey soils;
- limiting rooting depth of many crops as a function of Al toxicity and/or Ca deficiency in subsurface soil layers.

These points emphasize the need for appropriate management technologies to increase the probability of success when incorporating cerrado soils into the crop production process.

In spite of all these problems, a break-through in agricultural development has taken place in the area during recent decades, mainly involving food crops, pasture and coffee. Yield levels of some of these crops exceed national averages. Further, in 1992 they contributed nearly 20 million tonnes of grains (28 percent of Brazilian production), 43 percent of soybeans, 3 percent of the wheat, 14 percent of dry beans, 24 percent of the rice, 9 percent of

**Table 1.** Economic balance of the liming effect in three crops in Brazil.

Lime rate in first year tonnes/ha	Production increase after liming, kg/ha	
	First year	Period under review
Five years of corn		
3.0	422	7,877
6.0	600	11,619
9.0	1,250	13,777
Three years of soybeans		
1.5	473	1,746
3.0	513	2,357
4.5	645	2,610
Four years of cotton		
1.5	32	1,072
3.0	245	2,609
6.0	442	4,092

Source: Rajj & Quaggio, 1984

the sugarcane and 21 percent of the coffee, all on 10 million ha (FIBGE, 1993). Moreover, 35 million ha of improved pastures are producing 40 percent of Brazil's meat and 12 percent of its milk production. The potential of this region is considered by Norman Borlaug, Nobel Peace Prize winner in 1970, as the last great agricultural frontier of the world (Borlaug and Dowsell, 1993). Recent estimates suggest the area can produce 250 million tonnes of grains, 12 million tonnes of meat and 90 million tonnes of perennial crops (Macedo, 1995); (Lopes and Guilherme, 1994).

## Liming

Liming is an essential management practice for non acid-tolerant crops to correct low pH and Al toxicity (Table 1). The average rates of aglime are 3 tonnes/ha (range 1 to 5), broadcast and incorporated as deep as possible to help increase rooting depth and, thus, tolerance to dry spells during the cropping (rainy) season. For established peren-

nial crops, improved pastures and grain crops under no-till or minimum tillage, rates of lime are in general one-fourth normal rates.

Since most of these low pH soils are also deficient in Ca and Mg, dolomitic lime or Mg is most commonly recommended. The two methods commonly used to evaluate lime needs in this region are based upon Al and Ca + Mg levels and an increase in base saturation to a more adequate level for a given crop. Calculations for lime recommendation according to these methods are as follows:

### 1.0 Al and Ca + Mg method (Sousa et al., 1989)

#### 1.1 Soils with > 20% clay and Ca + Mg < 2 meq/100 cm<sup>3</sup>:

$$\text{Rate of lime (t/ha)} = (2 \times \text{meq Al}/100 \text{ cm}^3) + (2 \cdot \text{meq Ca} + \text{Mg}/100 \text{ cm}^3)$$

#### 1.2 Soils with > 20% clay and Ca + Mg > 2 meq/100 cm<sup>3</sup>:

$$\text{Rate of lime (t/ha)} = 2 \times \text{meq Al}/100 \text{ cm}^3$$

#### 1.3 Soil with <20% clay:

$$\text{Rate of lime (t/ha)} = 2 \times \text{meq Al}/100 \text{ cm}^3 \text{ or}$$

$$\text{Rate of lime (t/ha)} = 2 \cdot \text{meq Ca} + \text{Mg}/100 \text{ cm}^3,$$

applying the higher of the two rates

### 2.0 Increase base saturation method (Quaggio et al., 1983)

$$\text{Rate of lime (t/ha)} = T (V_2 - V_1)/100 \text{ where } T = \text{CEC at pH } 7.0;$$

V<sub>2</sub> = base saturation adequate for a given crop, V<sub>1</sub> = base saturation at pH 7.0.

The residual effects of these rates of lime, in general, can vary from 3 to 5 years. Lime should be broadcast and incorporated at least 60 to 90 days before planting or fertilization.

## Amelioration of Subsoil Acidity

In most cases, the beneficial reactions of lime occur only in the incorporation layer. Low levels of Ca and Al toxicity can still restrict rooting depth in sub-surface soil layers (Lopes, 1983; Goedert, 1987). Under these conditions the use of agricultural gypsum, by-product of phosphoric acid production, has been shown to be an efficient management technology to increase rooting depth below the surface layer (Figure 1).

It is extremely important to evaluate acidity parameters (pH, Ca and Al levels) in the surface layer (0 - 20 cm), and to depths of 20 to 40 and 40 to 60 cm. For perennial crops, eval-

uations should also include the 60 to 80 cm depth. For areas with 0.3 meq Ca/100 cm<sup>3</sup> or less and/or 0.5 meq Al/100 cm<sup>3</sup> or more and/or more than 30 percent Al saturation of the effective CEC in these sub-surface layers, the use of agricultural gypsum at higher rates is recommended to move Ca down to these layers and/or to reduce Al toxicity throughout the soil profile (Lopes, 1983; Lopes, 1986).

The simplest soil parameter to evaluate rates of gypsum under these conditions is percent clay. Two approaches are most commonly used:

1. Rate of gypsum (kg/ha) = 300 + (20 x % clay), developed by Lopes et al., 1986, to improve the 20 to 40 cm layer.
2. Rate of gypsum (kg/ha) = 50 x % clay, developed by Sousa et al., 1992, to improve the 20 to 60 cm layer. For perennial crops, multiply the results by 1.5.

Improvements in yields from gypsum use in these soils, mainly due to increased rooting depth and more efficient use of subsoil water and nutrients, are reported as: 72 percent for corn, 59 percent for wheat, 14 percent for soybean, 30 percent for coffee, and 80 percent for lucerne. Significant responses have also been obtained for mango, orange and sugarcane (Sousa, Lobato and Rein, 1995).

The recommended rates of gypsum are generally surface broadcast at 60 to 90 days after liming. Residual effects last from 5 to 15 years.

### Build-up Phosphate Fertilization

Build-up phosphate fertilization in these soils with extremely low levels of available P has been a crucial step to achieving adequate and economic yields in a short period of time (Figure 2). Average soil P content is 0.4 parts per million (ppm), and soil P fixation capacity is high. There is a well-defined relationship between clay percentage and rate of P needed to build levels of soil P in these low activity clay soils. According to Lopes (1983) 3 to 5 kg of soluble P<sub>2</sub>O<sub>5</sub> for each one percent of clay, usually broadcast in the first year and incorporated by disking before planting, followed by small maintenance crop fertilization, are recommended to achieve the desired yield goal within 3 years of incorporation.

Another common approach to gradually build P status in these soils is to apply a little excess P<sub>2</sub>O<sub>5</sub> (20 kg/ha above normal maintenance crop fertilization) at planting. This rate should be applied for 5 to 6 years. After P soil levels reach medium to high, only maintenance fertilization is used (Sousa, 1989).

For grain crops, sugarcane and coffee, soluble P fertilizers (i.e. single superphosphate, triple superphosphate, thermophosphate or highly reactive rock phosphates), have been confirmed as the most efficient sources for use following liming. Due to the low reactivity of most Brazilian rock phosphates, these products are usually recommended for direct application only for opening new areas with pastures of acid tolerant species (Smyth and Sanchez, 1982; Goedert and Lobato, 1984; Goedert and Lopes, 1988). Since liming reduces the agronomic effectiveness of low reactivity rock phosphates even more, lime in these cases is recommended at one-fourth the normal rates (Lopes and Guilherme, 1989).

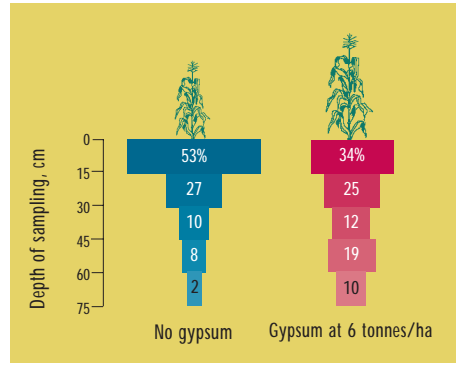


Figure 1. Relative distribution of a corn root system with and without gypsum in a clayey Oxisol in central Brazil. Source: Sousa & Ritchey, 1986

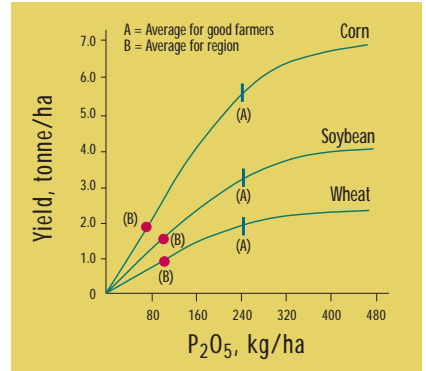


Figure 2. Corn, soybean and wheat yields under non-irrigated conditions, as a function of build-up rates of phosphate fertilization. Source: Wagner, 1986

## Build-up Potash Fertilization

Build-up of K is recommended in areas with less than 30 ppm of available K and more than 15 percent clay (Sousa, 1989). Rates normally vary from 50 to 100 kg K<sub>2</sub>O/ha, depending upon soil texture, crop demand, etc. Rates can also be calculated to achieve 3 to 5 percent K saturation at pH 7.0. (Lopes and Guidolin, 1989). Potash fertilizers should be broadcast along with build-up phosphate fertilization.

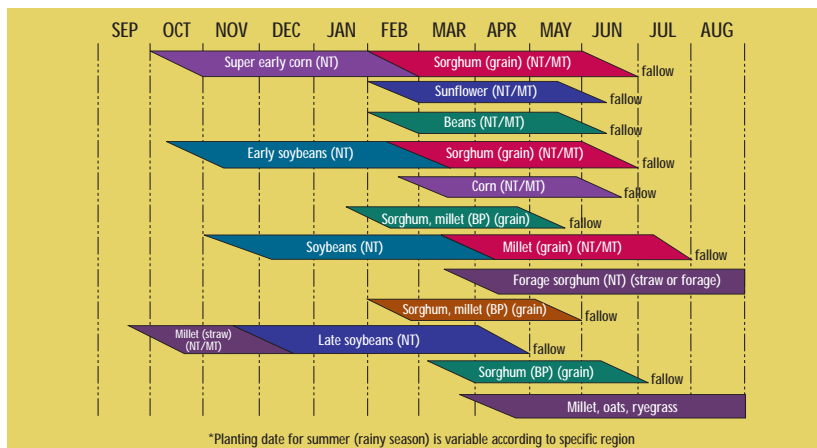
## Build-up Micronutrient Fertilization

The concept of build-up fertility of cerrado soils also includes micronutrients. Micronutrient fertilizers can be broadcast applied to those soils with naturally low availability (Zn, Cu, B and Mo). Several combinations of micronutrients are available for use according to specific problems in a given micro region of the cerrado.

## Organic Matter Management

The great majority of the cerrado soils contain low activity clays, medium organic matter content and very low CEC, more than 70 percent of which is due to the organic fraction. Under management systems that include monocropping, conventional tillage and use of lime and fertilizers, organic matter depletion is fast and can reach unsustainable low levels after a few years of cultivation. Under these conditions it is extremely important to make use of a combination of more sustainable agricultural practices to avoid rapid declines in organic matter content. Practices such as crop rotation including improved pastures, green manure, minimum or no-tillage, cover crops, mulching for small farms, manure and adequate crop residues, are important management tools. The rapid increase in no-till in this region in recent years is certainly a key factor for future sustainable agricultural development. Common crop sequences used under minimum or no-tillage are presented in Figure 3.

Figure 3. Commonly used crop succession for minimum (MT) or no-tillage (NT) in the cerrado region; BP = broadcast planting. Source: Sousa, 1995



## Maintenance Fertilization

Following the build-up program, adequate and balanced maintenance programs are essential to maintain soil fertility and optimum crop production potential.

## Present Land Use and Potential of the Cerrado Region

The present agricultural development of the cerrado region is the result of an integrated strategy, developed by the Cerrados Agriculture Research Center (CPAC), founded in 1975. It also involves other units of EMBRAPA (Brazilian Agriculture Research Enterprise), state

research institutes, state and federal universities, as well as international institutes/universities such as CIAT, JICA, ORSTOM, CIRAD, TROP SOIL, Cornell University and North Carolina State University (Macedo, 1995).

A broad diagnosis of the major limitations for agriculture improvement was made in the 1970s, identifying the priority problems as a base to establish the research program:

- low knowledge of the natural resources
- irregular distribution of rain and dry spells
- low soil fertility
- soil degradation
- occurrence of pests and diseases
- inefficient production systems

Research projects were organized into three programs (Macedo, 1995):

- Natural Resource Evaluation
- Soil and Water Management
- Production Systems.

**Table 2.** Production of grain crops and beef cattle in the cerrado region.

Activity	Area, million ha	Productivity, t/ha/year	Production, million tonnes
Grain crops			
Rainfed	10.0	2.0	20.0
Irrigated	0.3	3.0	0.9
Beef cattle	35.5	0.05	1.7
<b>Total</b>	<b>45.3</b>		<b>22.8</b>

Source: Macedo, 1996

**Table 3.** Cerrado region production as a percent of totals for all of Brazil.

Output	% of total	Output	% of total
Soybeans	42.9	Coffee	21.2
Rice	24.4	Cassava	11.3
Corn	22.9	Cotton	12.1
Beans	14.2	Sugarcane	9.3
Wheat	3.1	Beef cattle	40.5

Source: FIBGE, 1993

## Present Land Use

It is estimated that of the present 47 million ha (23 percent of the cerrado area) now cultivated, 10 million ha are grain crops under rainfed conditions, 0.3 million ha are grain crops under irrigation, 35 million ha are improved pastures mainly for beef cattle, and 2 million ha are perennial crops, including coffee, fruits and reforestation (Table 2). The 22.8 million tonnes of food produced in the region account for one-third of total Brazilian production.

Detailed information about specific crops and their production in relation to total Brazil production is presented in Table 3. It is of interest to note that soybeans, coffee and beef cattle account for 43 percent, 21 percent, and 40 percent of Brazil's production, respectively.

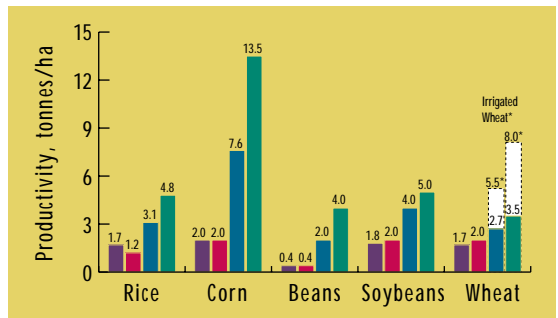
The present index of crop productivity in the cerrado region is a little above the Brazilian average, but is still below that obtained by farmers that use adequate available technologies. Average productivity in the cerrado region compared to the average for Brazil is shown in Figure 4. Some of the production is comparable to that obtained in the better soils of the world.

## Potential Use

According to Macedo (1995), if one considers the increase in productivity obtained by cerrado farmers who utilize the technologies already available, it is perfectly feasible to obtain yields of 3.2 tonnes of grain/ha/year under rainfed conditions, 6 tonnes under irrigation and 200 kg of meat/ha/year. This means that it would be possible to increase food production in the region to nearly 100 million tonnes, enough to feed a population of 250 million.

In the short term, the use of available technology to increase crop and beef cattle productivity in the area deserves the total attention of agriculturists. Technology is also a very powerful tool for use in environmental preservation. It diminishes the rate of deforestation of the more fragile ecosystems, helps to maintain biodiversity, and makes better use of the

*Figure 4.* Average productivity and potential for selected crops in the cerrado region as compared to the average for Brazil. Source: Adapted from Macedo, 1995



**Table 4.** Food production using available technology in the potential area of the cerrado in Brazil.

Activity	Area, million ha	Productivity, t/ha/year	Production, million tonnes
Grain crops			
Rainfed	60.0	3.2	192
Irrigated	10.0	6.0	60
Beef cattle	60.0	0.2	12
Perennial crops	6.0	15.0	90
<b>Total</b>	<b>136.0</b>		<b>354</b>

*Assumptions: One-third of the area (71 million ha) maintained for environment preservation; water availability to irrigate 10 million ha: average productivities would increase to levels compatible with available technology.*

*Source: Macedo, 1995*

natural resources.

In the long term, however, one must consider the total potential of the cerrado region as an important and probably the last great continuous agricultural frontier to help to produce food to satisfy the future demand of the growing world population.

If 136 million of the 204 million ha of the cerrado region can be incorporated into a sustainable production system for the medium to long run, it would be possible to produce around 350 million tonnes of food in the area (Table 4). In reaching this production level, the cerrado agricultural frontier could be expanded by 89 million ha, while protecting 71 million ha for environmental preservation.

It should be stressed, however, that several factors concerning structural, economic and political aspects have to be considered in order for the cerrado region to achieve a more complete development for agriculture, livestock and reforestation activities.

The question is not only a matter of availability of sustainable technology for soil management in this region, but also the need for special programs to improve today's infrastructure of roads, railroads, storage facilities, electricity and water supply, among others. Special lines of credit mainly related to liming and build-up phosphate fertilization, as well as reduction of taxation for agricultural inputs and products, are essential to expand the rational development of the area.

Above all, a necessary political decision is to adopt medium to long-term agricultural policies as a part of a broad food security program for the country. The beneficial implications of such policies must not be considered only for the agriculture-livestock-forestry sectors. The development already reached in one-fourth of the cerrado region has demonstrated it is possible to reduce excessive migration of the rural population to big cities. Hundreds of small, well planned towns, less than 15 years old and built as a result of the development of these distant areas, have living conditions better than many old traditional towns near the coast. The social benefits of such development programs in the past extend to the cerrado region.

Finally, it is important to mention that under present conditions in the Brazilian economy, the philosophy for rural activities is to first increase productivity in the area already under cultivation by using advanced sustainable management. Only then is the agricultural frontier expanded.

It is now recognized that increased crop-livestock-forestry production in the cerrado region by using available sustainable technologies constitutes a very powerful environment preservation instrument. Such production contributes to reduced rates of deforestation, including the Amazon Forest and other more fragile ecosystems not satisfactory for intensive use, but with high potential for irreversible degradation.

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## Bibliography

- Borlaug, N.E. and C.R. Dowsell. Fertilizer: to nourish infertile soil that feeds a fertile population that crowds a fragile world. Keynote address at the 61st Annual Conference, International Fertilizer Industry Association (IFA), May 24-27, 1993, New Orleans, Louisiana, USA, 18 p.
- FIBGE. 1993. Produção agrícola municipal. Fundação Instituto Brasileiro de Geografia e Estatística.
- Lopes, A.S. 1983. Solos sob "cerrado": características, propriedades e manejo. Associação Brasileira para a Pesquisa da Potassa e do Fosfato, Piracicaba, SP. 162 p.
- Lopes, A.S. 1986. Calagem e gesso agrícola. Encontro técnico sobre gesso agrícola. Fosfertil/Petrofertil, Belo Horizonte, MG. 58 p. (mimeo).
- Lopes, A.S. and J.A. Guidolin. 1989. Interpretação de análise de solos: conceitos e aplicações. ANDA, São Paulo, SP, Boletim Técnico N° 2, 3ª edição. 64 p.
- Lopes, A. S. and L.R.G. Guilherme. 1994. Solos sob cerrado: manejo da fertilidade para produção agropecuária. ANDA, São Paulo, SP, Boletim Técnico N° 5, 2ª edição. 62 p.
- Macedo, J. 1995. Prospectives for the rational use of the Brazilian Cerrados for food production. Planaltina, EMBRAPA-CPAC. 19 p.
- Goedert, W.J. 1987. Management of acid tropical soils in savannas of South America. p. 109-127. *In*: IBSRAM (International Board for Soil Research and Management). Management of acid tropical soils for sustainable agriculture: proceedings of an IBSRAM inaugural workshop. Bangkok, Thailand.
- Goedert, W.J. and E. Lobato. 1984. Avaliação agrônômica de fosfatos em solos de cerrado. R. bras. Ci. Solo, Campinas, SP, 8:97-102.
- Goedert, W.J. 1989. Região dos cerrados: potencial agrícola e política para o seu desenvolvimento. *Pesq. agropec. bras.*, Brasília, DF, Brasil, 24(1):1-17.
- Goedert, W.J. and A.S. Lopes. 1988. Eficiência agrônômica de fertilizantes fosfatados para culturas anuais, perenes, pastagens e reflorestamento. p. 24-29. *In*: Seminário sobre recuperação de fósforo. São Paulo, SP, IBRAFOS.
- Quaggio, J.A. 1983. Critérios para calagem em solos do estado de São Paulo. Unpublished manuscript M.S. thesis. Escola Superior de Agricultura "Luís de Queiroz," Piracicaba, SP, 76 p.
- Raij, B. van and J.A. Quaggio. 1984. Uso eficiente de calcário e gesso na agricultura, p. 323-346. *In*: Espinosa, W. and A.J. de Oliveira (ed.). Simpósio sobre fertilizantes na agricultura brasileira. Brasília, D.F. Anais..., EMBRAPA-DEP.
- Sousa, D.M.G. de. 1989. Calagem e adubação da soja no cerrado. Porto Alegre, DEAGRO/ADUBOS TREVO, S/A, p. 17.
- Sousa, D.M.G. de, T.A. Rein, E. Lobato and D. Ritchey. 1992. Sugestões para diagnose e recomendação de gesso em solos de cerrado. p. 138-158. *In*: II Seminário sobre o uso de gesso na agricultura. Uberaba, MG. Anais..., São Paulo SP, IBRAFOS.
- Sousa, D.M.G. de, E. Lobato, and T.A. Rein. 1995. Uso de gesso agrícola nos solos dos cerrados. p. 20. Planaltina, DF, EMBRAPA-CPAC, Circular Técnica N° 32.
- Sousa, D.M.G. de and K.D. Ritchey. 1986. Correção de acidez subsuperficial: uso de gesso no solo do cerrado, p. 91-113. *In*: Decher, A.R. and Q.A. C. Carmelo de (ed.). Simpósio avançado de química e fertilidade do solo. Campinas, SP, Fundação Cargill, p. 91-113.
- Sousa, W. de. 1995. Plantio direto. p. 32-45. Manchete Rural. Rio de Janeiro, RJ, N° 98, agosto.
- Smyth, T.J. and P.A. Sanchez. 1992. Phosphate rock dissolution and availability in cerrado soils as affected by phosphorus sorption capacity. *Soil Sci. Soc. Am. J.*, Madison, Wisconsin, USA, 46:339-345.
- Wagner, E. 1986. Desenvolvimento da região dos cerrados. *In*: Goedert, W.J. (ed.) "Solos dos cerrados" Tecnologia e estratégia de manejo. São Paulo, SP, Editora Nobel, 19-31.

# Phosphate and Potash Use in Vegetable Crops

By B.S. Prabhakar

*India is endowed with favorable tropical, sub-tropical and temperate climates, making it conducive for producing high quality, high value vegetables year round in various parts of the country. At present, 50 million tonnes of vegetables are produced from about 5 million hectares which account for less than two percent of the cropped land.*

There is an appalling gap between potential yields and actual yields harvested by farmers. For most vegetable crops, yields realized are less than 50 percent of the potential (Table 1). By the year 2000, India will need to produce 100 million tonnes of vegetables from less than 6 million hectares by increasing productivity from 10 t/ha to 15 or 20 t/ha. This task calls for better crop husbandry including the use of optimum rates of nitrogen (N), phosphorus (P), and potassium (K). On average, a 35 t/ha crop of vegetables removes 151, 57 and 195 kg N, P<sub>2</sub>O<sub>5</sub> and K<sub>2</sub>O, respectively (Table 2).

## Phosphorus Management

About 98 percent of India's soils require fertilizer P application to augment crop yields. Crop recovery from added P seldom exceeds 20 percent during the year of application. Placement of P fertilizer at 5 cm depth results in better absorption and utilization of applied P, effecting savings of up to 20 percent in tomato and onion and up to 40 percent in brinjal. Okra also responds to placement of P at 10 to 15 cm depth. French bean varieties with high yield potential (Akra Komal, IHR 909 and Contender) exhibit higher P uptake and utilization. Genotypes with low yield potential exhibit low P utilization.

Although P uptake by the first crop is usually below 20 percent, with smaller amounts being absorbed by the subsequent crops, applied P utilization can be increased with intensive cropping systems.

Table 1. Area, production, productivity and potential of vegetable crops (NHB 1992/93).

Crop	Area, 1,000 ha	Production, 1,000 tonne	Productivity, t/ha		
			Actual	Potential	Percent
Potato	1,260	20,284	16	40	40
Onion	381	5,781	15	35	43
Tomato	309	4,850	16	50	32
Cabbage	216	4,357	20	70	29
Cauliflower	222	4,221	19	50	38
Okra	222	2,487	9	20	45
Peas	194	1,492	8	20	40
Others	2,240	27,596	12	40	30
Total	5,103	71,006	14	40	35



**Table 2. Nutrient removal by some vegetable crops.**

Crop	Yield, t/ha	Nutrient Removal, kg/ha		
		N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Beans	15	130	40	160
Cabbage	70	370	85	480
Carrot	30	125	55	200
Cauliflower	50	250	100	350
Cucumber	40	70	50	120
Okra	20	60	25	90
Onion	35	120	50	160
Radish	20	120	60	120
Tomato	50	140	65	190
Peas	20	125	35	80
Mean	35	151	57	195
Nutrient Ratio		2.65	1.00	3.42

In a cropping system including French bean/cabbage/tomato fertilized with two levels of P, the residual, direct and cumulative effects of P fertilization depended on the crop in sequence and the level of P added to the previous crop.

Evaluation of P sources has mostly involved those with varying water solubility. For short duration vegetable crops, water soluble P is superior to citrate soluble P, though the latter holds some advantages in vegetable rotations.

Most of the vegetable crops favor basal application because of their poor ability to utilize soil P in early crop growth stages. Split applications of P may be useful in cases where the initial supply of the nutrient is adequate. Soaking seeds in P solution and dipping seedlings in a P solution or slurry have been found useful in meeting the initial requirement. Coating single superphosphate (SSP) with a biogas slurry or cow dung has also been shown to increase the efficiency of P fertilizer.

## Potassium Management

In India, about 13 percent of the soils are low, 53 percent medium and 34 percent high in available K. Though the removal of K by vegetable crops is of the same order or higher than that of N, its application is nowhere near that of N. The response to added K varies with the crop, but its application to each individual crop in a sequence is beneficial.

Muriate of potash is the most common source for the supply of K. However, root and bulb crops often respond more to potassium sulfate.

## Future Fertilizer Needs

Fertilizer recommendations for vegetable crops from different parts of India show that these crops require NPK in ratio of 2:1:1 (Table 3). However, nutrient ratios applied by the growers vary significantly from that recommended.

It is estimated that the present population of 900 million may reach one billion by the turn of the century and 1.7 billion by 2025. Whether India's farmers will be able to produce 100 million tonnes of vegetable crops by 2000 and 170 million tonnes by 2025 will depend largely on government policies.

Imbalances in productivity in different regions and environmental concerns about high input, intensive agriculture are some of the issues affecting vegetable production. However, we cannot lose sight of the fact that the productivity levels of major vegetables are far below the projected yield levels needed, and the major constraint to higher productivity is still the limited use of mineral fertilizers. Export oriented production of vegetables under protected

**Table 3. Fertilizer recommendations for some vegetable crops.**

Crop	Nutrient, kg/ha		
	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O
Cabbage	150	125	100
Cauliflower	150	60	40
Tomato	110	60	95
Brinjal	120	80	80
Okra	60	50	30
Carrot	56	28	56
Radish	84	30	30
Onion	135	45	22
Peas	50	50	25
Bitter Gourd	56	28	28
Mean	96.21	51.71	53.14
NPK Ratio	2	1	1

structures is also dependent on the use of these commercially produced fertilizers.

The production of 100 million tonnes of vegetables from 8 million hectares by 2000 and 170 million tonnes by 2025 will require 0.35 and 0.5 million tonnes each of P and K, respectively (Table 4). During the same periods, India will need 140 and 200 million tonnes of farmyard manure at the recommended rate of 25 t/ha. Its application is an accepted and popular practice followed by vegetable growers. Any correction in supply of nutrients through organic sources is not going to reduce the demand for mineral fertilizer plant nutrients.

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**Table 4. Projection of plant nutrient needs of vegetable crops.**

Particulars	Year		
	1995	2000	2025
Population (m)	900	1,000	1,700
Requirement of vegetables (m.t.)	90	100	170
Area under vegetables (m.ha.)	5	6	8
Productivity (t/ha)	14	20	30
Farm yard manure (m.t.)	125	150	200
Nitrogen (m.t.)	0.50	0.70	1.00
Phosphorus (m.t.)	0.25	0.35	0.50
Potash (m.t.)	0.25	0.35	0.50
Total NPK (m.t.)	1.00	1.40	2.00

(m = million)

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## Liu Rongle Joins PPI/PPIC Beijing Staff as Agronomist

Mr. Liu Rongle has joined the international staff of PPI/PPIC.

He was appointed to the position of Technical Assistant (Agronomist) in the Beijing office on May 1, 1996. He will be assisting Dr. Jin Ji-yun, Deputy Director of the PPI/PPIC China Program, in agronomic research and education efforts with focus on north China.

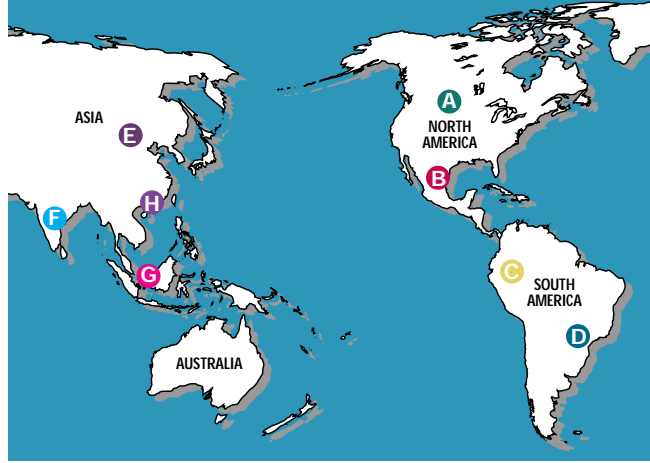
"Mr. Liu brings a strong background in soil and fertilizer research to our China program," said Dr. David W. Dibb, President of PPI.

During 1986-1995, Mr. Liu was employed as assistant and associate professor at the Sciencetech Documentation and Information Center of the Chinese Academy of Agricultural Sciences (CAAS), working on soil and fertilizer related information processing and retrieving. Before joining PPI/PPIC, Mr. Liu had transferred to the Science and Technology Management Department of CAAS, as an associate professor for coordinating national research projects.

Born in Hebei, China, Mr. Liu completed his undergraduate training in agronomy at Hebei Agricultural University in 1982-83. He continued with graduate study at CAAS and received his M.Sc. Degree in Soil Science in 1986.

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# Meet the PPI/PPIC International Staff



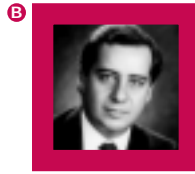
Shown here are staff serving PPI/PPIC international programs, with agronomic research and education efforts in 32 countries. Letters beside names correspond to letters on map to designate locations.



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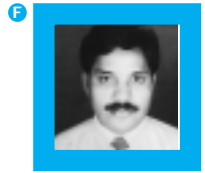
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# Precision Nutrient Management in Intensive Irrigated Rice Systems – The Need for Another On-Farm Revolution

By A. Dobermann and K.G. Cassman

*The potential for developing rice varieties for irrigated systems with increased nitrogen (N), phosphorus (P), and potassium (K) use efficiency will require many years of research and improvements in selection methods used in breeding programs. Thus, improvement in nutrient use efficiency in irrigated rice over the next 10 years must focus on better soil and crop management. At issue is whether the management strategies practiced by rice farmers are adequate to maintain the current yield levels over the long term and to support future yield increases needed to meet growing demand.*

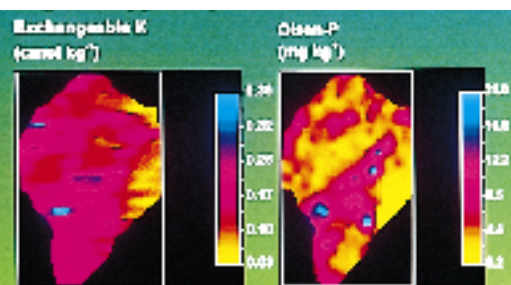


Figure 1. Nutrient depletion due to intensive rice cropping: K and P status in rice soils of Nueva Ecija, Philippines (19,196 ha).

479 million tonnes in 1990 will be needed to meet Asia's estimated future requirements of 686 million tonnes for the year 2025. Much of this increase must come from existing irrigated land (that is already now harvested twice a year) since a net increase in irrigated area for lowland rice is not to be anticipated.

This increase in yield levels will lead to a marked increase in net nutrient removal from rice fields. Total net K removal, for example, already exceeds the total K fertilizer consumption in south and southeast Asia by a large margin, and it is likely that this gap will widen further.

The K requirements of rice vary from 17 to 30 kg K per tonne of grain. For yields above 8 t/ha, total K uptake exceeds 200 kg/ha .

In irrigated rice areas of Asia the amount of K annually cycling from the soil into rice plants is in the range of 7 to 10 million tonnes. About one million tonne of K is removed with harvested grain alone.

Rice has been grown as a foodcrop for more than 6,000 years in Asia. Today, more than 90 percent of global rice supplies are produced and consumed in Asia, contributing 30 to 75 percent of dietary calories for populations in those countries.

Irrigated rice accounts for 75 percent of the overall rice production in Asia. Average yields must rise from 4.9 t/ha in 1990 to 8.0 t/ha by the year 2025 to meet increased demand from population growth.

Further intensification of lowland rice systems that produced

Researchers at the International Rice Research Institute (IRRI) have analyzed a number of long-term experiments on continuous, irrigated rice systems in Asia. They suggest that under continuously submerged conditions, the N supplying capacity of the soil is reduced, leading to a decreased yield contribution from nutrient inputs.

Researchers had observed a consistent yield decline trend during dry seasons at the IRRI Research Farm between 1968 and 1991 at N rates of 150 kg/ha.

There are now clear indications from long-term fertility experiments in irrigated rice systems of developing Asia that negative P and K balances may impede N efficiency. Some of this research was begun as early as 1964 and includes sites at which the initial soil fertility status was high.

Table 1 shows data from 11 sites in China, India, Indonesia, Philippines and Vietnam, most of which produced net negative K balances for all treatments and net negative P balances for treatments without P inputs when monitored in 1993 (Dobermann et al., 1995).

Indigenous nutrient supply varies widely among rice fields within small domains, as illustrated in Figure 1. However, blanket prescriptions for the rate and timing of fertilizer applications are presently issued by national research and extension authorities for large recommendation domains. In many cases, farmers do not follow those blanket recommendations, but they also do not adjust their fertilizer rates according to soil nutrient supply. Achieving and sustaining average yields of 7 to 8 t/ha will require improved nutrient management strategies that focus on increasing the use-efficiency of nutrients from both indigenous and external sources such as fertilizers.

Since current fertilizer management practices in intensive, irrigated rice systems are not tailored to differences in indigenous nutrient supply and crop demand, a new concept for integrated nutrient management is proposed. The objectives and tactics for management differ for each essential nutrient.

**Table 1.** Mean partial net P and K balances in different fertilizer treatments of long-term fertility experiments for irrigated rice in five Asian countries.

Treatment	Phosphorus (10 sites, 1993)					
	Olsen-P mg/kg	Grain yield kg/ha	Fertilizer P input	Recycled P in stubble	Total P uptake	Net P balance
kg P/ha						
Control	3.9	3,341	0	0.6	7.6	-7.0
+N	3.3	4,654	0	0.6	8.5	-7.9
+NP	9.5	5,530	20	2.1	17.2	4.9
+NK	3.3	5,112	0	0.5	8.5	-8.0
+NPK	9.4	6,189	20	2.0	18.3	3.7
Treatment	Potassium (9 sites, 1993)					
	Extract K cmol/kg	Grain yield kg/ha	Fertilizer K input	Recycled K in stubble	Total K uptake	Net K balance
kg K/ha						
Control	0.279	3,277	0	11	54	-43
+N	0.260	4,565	0	14	71	-57
+NP	0.251	5,426	0	12	75	-63
+NK	0.326	4,795	38	18	90	-34
+NPK	0.312	5,855	44	25	111	-42

China, India, Indonesia, Philippines, Vietnam

- Dynamic soil- and plant-based management is needed for N. The ability to adjust the quantity of applied N in relation to variation in the indigenous N supply is as important as the timing, placement and source of applied N (Peng et al., 1996; Cassman et al., 1996). Therefore, N management is based on these factors.
  - Estimation of crop demand, potential indigenous nutrient supply, and recovery from applied inorganic and organic sources over time to predict the total amount of applied N that is needed.
  - Estimation of soil N release during early growth stages to identify the need for a basal N application.
  - Monitoring of plant N status to optimize timing of split applications in relation to crop demand and soil N supply.
- Management of P and K requires a long-term strategy because neither P nor K is easily lost or added to the root zone by the biological and chemical processes affecting N (nitrification-denitrification, NH<sub>3</sub> volatilization, biological N fixation, leaching). Therefore, the issue of maximizing the recovery efficiency of fertilizer P and K is less important than predicting the need for applied nutrients and the amount to apply. However, management must emphasize the maintenance of available soil nutrients to insure that soil P and K supply does not limit crop growth and thus reduce N use efficiency. Changes in potential indigenous nutrient supply can be predicted as a function of the nutrient balance. Key components of P and K management include the following.
  - Estimation of crop demand, potential indigenous nutrient supply, and recovery from applied inorganic and organic sources over time to predict the amount of applied P and K required to sustain a targeted yield level.
  - Knowledge of the relationship between the P and K balance and changes in potential indigenous nutrient supply over time.
- Diagnosis of potential deficiencies is the key management tool for nutrients such as magnesium (Mg), zinc (Zn) and sulfur (S). Once identified as a problem, deficiencies can be alleviated by regular or one-time measures as part of a general fertilizer/soil use recommendation. Similarly, diagnostic criteria are needed to identify other nutritional disorders such as salinity, iron (Fe) toxicity, or boron (B) toxicity to make adjustments in the N, P, and K management that account for these limitations or to alter soil management practices to reduce the severity of these toxicities.

**Table 2.** Current and projected requirements of N, K, P, and S in irrigated rice systems of Asia. Estimates for 1991 are based on a harvest area of 74 million ha and an average yield of 4.9 t/ha (IRRI 1993). Estimates for 2025 assume a constant harvest area of 74 million ha and average yields of 8 t/ha to meet the projected rice demand of 592 million tonnes from irrigated systems (Cassman and Pingali, 1995). All values are given on elemental basis.

	Average nutrient content at harvest		Uptake per tonne of grain yield <sup>3</sup> kg/tonne grain	Annual removal with grain		Total annual uptake with grain and straw	
	Grain	Straw		1991	2025	1991	2025
	%		million tonnes/year				
Nitrogen <sup>1</sup>	1.05-1.40	0.50-0.80	15-22	3.8-5.1	6.2-8.3	5.4-8.0	8.9-13.0
Potassium <sup>1</sup>	0.25-0.33	1.30-2.00	15-25	0.9-1.2	1.5-2.0	5.4-9.0	8.9-14.8
Phosphorus <sup>1</sup>	0.15-0.25	0.05-0.10	2-4	0.5-0.9	0.9-1.5	0.7-1.4	1.2-2.4
Sulfur <sup>2</sup>	0.06-0.15	0.05-0.10	1.5-2.5	0.2-0.5	0.4-0.9	0.6-0.9	0.9-1.5

<sup>1</sup>N, P and K concentrations in grain and straw measured as the interquartile range of 192 plots of long-term fertility experiments with rice at 11 sites in China, India, Indonesia, Vietnam, and the Philippines (K. Cassman and A. Dobermann, unpublished data).

<sup>2</sup>Sulfur concentrations in grain and straw based on literature data (Yoshida 1981; Mohapatra et al 1993).

<sup>3</sup>Average total nutrient uptake in above-ground biomass (grain + straw) per tonne of grain yield adjusted to 14 percent moisture content.

In a model developed for maize by Janssen et al., 1990, a Nutrient Decision Support System (NuDSS) for irrigated rice has been initiated which provides the user with more cost-effective fertilizer recommendations. The approach is based on equations describing:

- (i) supply of N, P and K as a function of chemical soil test values,
- (ii) actual NPK uptake as a function of supply and
- (iii) grain yield as a function of NPK uptake (NPK interactions are acknowledged).

Besides on-farm nutrient omission plots, ion-exchange resin capsules can be used on-site to predict potential P and K supply, to identify the need for basal N application, and to assess possible nutritional disorders such as Zn or S deficiency. The resin capsule offers the potential for multi-element on-site soil nutrient extraction in flooded rice soils at different growth stages without the need for collecting and processing soil samples.

In order to calculate the partial P and K balance within the NuDSS, fertilizer input rates, above-ground plant uptake, and the amount of nutrients recycled with incorporated straw are used as a minimum data set.

Estimates of nutrients in recycled straw can be obtained from estimates of the stubble and straw left in the field (Table 1). On a dry matter basis, one tonne of rice straw contains 5 to 8 kg N, 0.5 to 1 kg P, 13 to 20 kg K, and 0.5 to 1.0 kg S (Table 2). Straw is either removed from the field, burned, piled or spread in the field, incorporated into the soil, or used as mulch for the succeeding crop. Each of these practices has a different effect on nutrient recycling and the overall nutrient balance, and thus must be accounted for in fertilizer recommendations.



## The Relationship Between Nutrient Uptake and Grain Yield

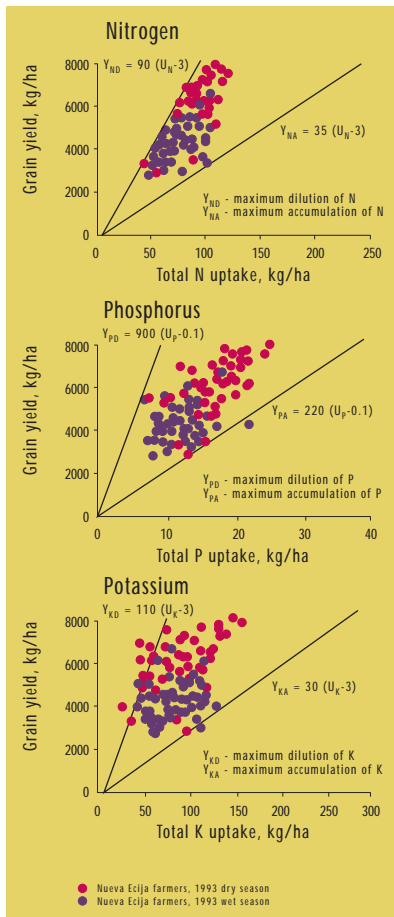
Physiological nutrient-use efficiency (PE) is defined as the grain yield increase per kg of nutrient accumulation in above-ground plant biomass. The relationship between grain yield and nutrient uptake is scattered within an “envelope” or range between two lines that define maximum accumulation (minimum PE) and maximum dilution (maximum PE) as shown in Figure 2. With a limited nutrient supply, there is maximum dilution of the nutrient in the plant, and uptake is not influenced by growth but only by supply (source limitation). Conversely, when the supply of a nutrient is large and growth is not limited by uptake, the internal nutrient concentration is high, and there is maximum accumulation (sink limitation). In this situation, growth is limited by other factors.

Using data from long-term fertility experiments, these relationships between grain yield and nutrient uptake were established for N, P, and K in modern rice varieties grown under irrigated conditions without limitations from pests, water, or other management factors (Figure 2). For N, this range was defined by two linear functions with a slope of 35 for maximum N accumulation ( $Y_{NA}$ ) and 90 kg grain/kg N for maximum N dilution ( $Y_{ND}$ ). The PE for P ranged from 220 to 900 kg grain per kg P. Depending on the availability of other nutrients, 16 to 33 kg P uptake/ha were needed to produce 8 tonnes grain ha. The slope of the relationship between grain yield and K uptake varied from 30 to 110 kg grain per kg K absorbed.

Improved nutrient management must focus on optimizing the PE of all major nutrients rather than maximizing the PE of a single nutrient. For example, very high PE of one nutrient (data points close to the line of maximum dilution) indicates that supply of this nutrient was a limiting factor. In such a situation, the full yield potential cannot be achieved. Therefore, integrated nutrient management should attempt to achieve PE values for N, P, and K that are approximately in the middle of the range enclosed by the lines of maximum dilution and of

*Nutrient omission plots can be established in farmers' fields to estimate grain yield and nutrient uptake supported by the indigenous soil nutrient supply. This plot received P and K fertilizer inputs but no N fertilizer, and therefore provides an estimate of soil N supply capacity. Similar omission plots can be established for P or K.*

Figure 2. Envelopes describing the range of the relationship between total uptake of N, P and K with grain yield (14 percent moisture content) in modern rice varieties grown under irrigated conditions. The regression functions describing maximum accumulation (A) and maximum dilution (D) of each element in the plant were derived from long-term experiments conducted at 11 sites in five countries. For comparison, data collected from 60 farmers in Central Luzon, Philippines, are plotted as symbols.



maximum accumulation. Plotting actual crop uptake vs. grain yield data within such an envelope may also serve as a diagnostic tool for assessing the actual nutrition status in farmer fields. For example, PE of P in most farmer fields of a study in Nueva Ecija was in the middle of the envelope, and we may conclude that P supply was sufficient. On many farms, however, PE of N in the dry season was close to the maximum dilution line, suggesting limitations to crop uptake due to insufficient N management. The same holds true for K on some farms.

The nutrient management strategy proposed here is a generic approach which, within the context of extension, is applicable to different spatial scales. However, because variation in potential indigenous nutrient supply is large, **the scale of nutrient management recommendation domains must change from large regions to farms, single fields, or even single parcels within a larger field.**

A move from blanket recommendations for large regions to farm- or field-specific management will require a gradual transition. Over the shorter-term, other cost-effective methods to help farmers achieve increased nutrient use efficiency should be further explored. Customary rules on timing of N

application or green leaf color charts could replace an expensive tool such as the chlorophyll meter. Readily available soil information such as maps, local knowledge, or simple agronomic soil classification systems may be used to improve fertilizer recommendations. In many countries of Asia, facilities for more sophisticated farmer support need to be built up. Included among these are: soil testing laboratories and a soil testing program, perhaps with the involvement of the private sector, fertilizer recommendation services, objective information about new fertilizer products, and use of mass media (radio, TV, newspapers) for extension of new technologies. Using a knowledge-intensive approach will also require a change in farmers' record keeping practices. Good estimates of yields and fertilizer use are required for single fields, and farmers need better means of measuring fertilizer doses more accurately.

## Conclusion

Precision nutrient management should be applied on Asia's 74 million ha of irrigated rice in order to meet the requirements for another economically successful, but environmentally friendly, on-farm revolution. **BCI**

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## Bibliography

- Cassman, K.G., A. Dobermann, P.C. Sta.Cruz, G.C. Gines, M.I. Samson, J.P. Descalsota, J.M. Alcántara, M.A. Dizon, and D.C. Oik. 1996a. Soil organic matter and the indigenous nitrogen supply of intensive irrigated rice systems in the tropics. *Plant Soil* (in press).
- Cassman, K.G., G.C. Gines, M. Dizon, M.I. Samson, and J.M. Alcántara. 1996b. Nitrogen-use efficiency in tropical lowland rice systems: Contributions from indigenous and applied nitrogen. *Field Crops Res.* 47:1-12.
- Cassman, K.G., S.K. De Datta, S.T. Amarante, S.P. Liboon, M.I. Samson, and M.A. Dizon. 1996c. Long-term comparison of agronomic efficiency and residual benefits of organic and inorganic nitrogen sources on irrigated lowland rice in the tropics. *Exp. Agriculture* (in press).
- Cassman, K.G., and P.L. Pingali. 1995. Intensification of irrigated rice systems: Learning from the past to meet future challenges. *GeoJournal* 35:299-305.
- Dobermann, A., K.G. Cassman, C.P. Mamaril, and J.E. Sheehy. 1996a. Management of phosphorus, potassium and sulfur in intensive, irrigated lowland rice. Paper presented at the workshop Nutrient Use Efficiency of the Cropping System(s). 13-5 December 1995, International Rice Research Institute, P.O. Box 933, Manila 1099.
- Dobermann, A., P.C. Sta.Cruz, and K.G. Cassman. 1996b. Fertilizer inputs, nutrient balance, and soil nutrient-supplying power in intensive, irrigated rice systems. I. Potassium uptake and K balance. *Nutrient Cycling in Agroecosystems* 46:1-10.
- IRRI. 1993. 1993-1995 IRRI rice almanac. International Rice Research Institute, P.O. Box 933, 1099 Manila, Philippines.
- Janssen, B.H., F.C.T. Guiking, D. Van der Eijk, E.M.A. Smaling, J. Wolf, and H. Van Reuler. 1990. A system for Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS). *Geoderma* 46:299-318.
- Mohapatra, A.R., A.K. Misra, and V. Sarkunan. 1993. Absorption pattern of secondary nutrients and micronutrients by high-yielding rice (*Oryza sativa*) varieties. *Indian J. Agric. Sci.* 63:586-588.
- Peng, S., F.V. Garcia, R.C. Laza, A.L. Sanico, R.M. Visperas, and K.G. Cassman. 1996. Increased N-use efficiency using chlorophyll meter on high-yielding irrigated rice. *Field Crops Res.* (in press).
- Yoshida, S. 1981. Fundamentals of rice crop science. International Rice Research Institute, P.O. Box 933, 1099 Manila, Philippines.

# Environmental Improvement Through Sound Fertiliser Practices

By Bob Freebairn and John S. Glendinning

*Research in the Central West of New South Wales has shown that good fertiliser practice can improve soil structure, increase soil organic matter levels, increase water infiltration rates and improve water use efficiency, as well as increase farm productivity and farm profitability.*

This research, conducted at Ulamambri, near Coonabarabran, was started in 1987. It shows that the benefits of fertiliser go far beyond the generally accepted role of simply increasing production at the expense of the environment.

The trial site had been a native pasture paddock for many years and was of very low productivity, the soil set very hard. Very little pasture growth was produced, even in the spring time when it is normally expected that pastures will produce a good body of feed. The area was commonly low in plant cover. Because the soil set so hard, when rain fell it was almost totally lost through run-off, often taking with it more of the valuable topsoil.

## Treatments

The trial was started because of the feeling amongst research and extension workers and landholders that animal production could be improved very significantly with good fertiliser practice and that better use could be made of the available moisture when rain fell. It was also felt that all this could add up to beneficial effects on a number of soil characteristics without any detrimental effects on the environment.

Soil tests before the trial was started showed quite high phosphorus(P) levels, but soil sulphur(S) was low. For this reason the only treatment applied to the trial area was to broadcast 2 kg/ha of subterranean clover. There were two annual applications at 100 kg/ha of S-fortified superphosphate, containing 5.6 percent P (12.8 percent  $P_2O_5$ ) and 42 percent total S.

No other fertiliser was applied over the first 9 years of the trial.



Soil erosion is one of the biggest problems facing agriculture.

## Results

**Organic Matter** – Soil tests on samples taken in 1996, 9 years after the trial commenced, showed that the organic matter content of the soil doubled from 1.8 percent organic carbon to 3.6 percent.

This effect on the soil organic matter is of major significance. It shows how productive pastures can restore the health of soils, for such things as a cropping phase, where organic matter has declined through over-cultivation. It is also of major importance in protecting the soil from loss due to erosion during very heavy rainfall events or stress periods brought about by drought conditions.

The protection of the surface layers of the soil also helps to conserve the important, high-fertility profile of the soil. When this part of the soil profile is lost due to erosion from whatever cause, a major part of the soil fertility and previous investment in fertilisers is also lost. In some cases, it may lead to loss of nutrients and other fertility components in dust storms; in others, it may be lost by water erosion and find its way into water courses, creeks and rivers and, in extreme cases, increase the problems of contamination by blue-green algae and the eutrophication of the water course.



*Stubble retention, reduced cultivation and improved pastures help prevent erosion.*

**Soil pH** – There was a small drop in soil pH over the period of the trial from 5.9 in 1987 to 5.7 in 1996, when measured in a weak solution of calcium chloride. This may have been an artifact due to seasonal variation in the soil or an effect due to sampling differences. In any event, it is of very minor extent and is something that is expected to occur when any form of improved agriculture is practiced. Such changes in soil pH are due in part to a build-up and leaching of soil nitrates and calcium (Ca) compounds, and release of organic acids in the soil; and partly to the removal of Ca compounds in the process of selling animal products off the farm.

**Water Use Efficiency** – Equally significant was the effect of fertiliser treatment on water infiltration. A test on the trial site found that the water infiltration rate, determined by measuring the rate of absorption of water from above ground cores, increased from 1.3 mm per minute to 10.5 mm per minute. This is a clear indication of better and faster retention of rainfall, especially following storm events.

The improved water infiltration led to greatly increased water use efficiency. Dry matter (DM) production from the fertilised and unfertilised areas was measured at key times of the year during the winter-spring period. Dry matter production at this critical time of the year was 567 kg/ha from the unfertilised area compared with 3,111 kg/ha from the fertilised area. This is equivalent to 2.03 kg DM/mm of rainfall from the unfertilised area compared with 11.13 kg DM/mm of rainfall from the fertilised area.

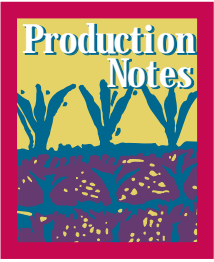
**Microbial Activity** – Another interesting effect of this application of fertiliser was on the level of microbial activity in the soil.

CSIRO at Armidale examined the trial site for microbial activity, an indication of the soil's biological health. The fertilised areas showed considerably higher rates of basal respiration and microbial carbon.

**Implications for Farm Management** – Similar beneficial effects to those shown in this trial should also apply to most well managed pasture improvement programs. Sound management is obviously a key consideration to ensure that the improved pasture species survive and that sufficient of the extra pasture production is retained to protect the soil. **BCI**

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## Using Comparative Advantages – An Example from China

Professor Li Yining, Head of the Department of Economics and Management, Beijing University, had these comments in the Hong Kong newspaper, *South China Morning Post* (October 16, 1995), "One of the most important decisions in a developing economy is knowing when and how to use a region's geographical features to their best advantage." He cited, as an example, how one county in southern China had made the transformation from financial gloom to a thriving economy by switching from corn to sugarcane production.

Long-term corn yields were poor, food supply was inadequate, farm income was low, and the entire county was in poor financial state. County leaders decided to do something about it. They cut corn hectareage and expanded the sugarcane growing area...because sugarcane yields were much higher. They also built a sugar refinery. As a result, sugar production expanded, generating more income for the county and the industrial sector.

The county's economy was revived. Farmer income increased and food was more abundant, largely due to three reasons.

Farm land converted to sugarcane was more productive. Further, land still in corn was managed more intensively, resulting in higher, more profitable yields.

The sugar refinery triggered industrial growth in the county, allowing the industrial sector to offer greater support to agriculture.

Increased per capita income brought about rapid economic changes. The domestic market was more prosperous; there was more money for education, construction, etc.

Professor Li Yining points out that each area (county) has its own comparative advantages. Success depends on how they are managed. He recognizes that convincing farmers to change can be difficult, but change is required to improve economic conditions. He concludes that if comparative advantage is not exploited, poor counties will continue to be poor and those counties with food shortages will require outside aid to survive.

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*Editor's Note: Professor Li Yining is also a Standing Committee Member of the National People's Congress.*

