Better Crops International

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Effect of Balanced Fertilization on Cocoa Yield

By Armando Uribe, Hernando Méndez, and Jairo Mantilla

A long-term study on cocoa fertilization demonstrates the benefits of building soil fertility levels for plantation crops.

Cocoa is either grown in low production systems under shade of other vegetation or in intensive production systems where trees are completely exposed to sunlight. Fertilization of shade cocoa commonly produces only modest yield increments. Fertilization of sunlight-exposed plantations generally results in significant yield responses because of greater photosynthetic activity. Despite their higher yield potential, sunlight-exposed plantations grown without fertilizer experience rapid yield declines with time and often suffer from early senescence. Research on cocoa response to fertilization is scarce in Colombia. This study was designed to evaluate response to balanced nutrition over five consecutive years.

The experiment was conducted in Santander, Colombia, in a four-year old plantation of mixed commercial hybrids. The site is 900 m above sea level. It has a mean annual precipitation of 3,000 mm and a mean annual temperature of 24° C. Soil chemical properties at the beginning and end of the study are presented in **Table 1**. Treatments used in the experiment included three rates of nitrogen (N): 50, 100, and 150 kg/ha; one rate of phosphorus (P): 90 kg P_2O_5/ha; and three rates of potassium (K): 50, 100, and 200 kg K_2O/ha. A check treatment received the common farmer practice of 2 kg chicken manure per tree. All experimental units received an annual application of 200 g dolomite/tree. Fertilizer application was split twice a year with applications made at the beginning of each rainy season.

Table 1. Average initial, intermediate and final soil test levels of the treatment plots where the highest yields were obtained (Santander, Colombia).

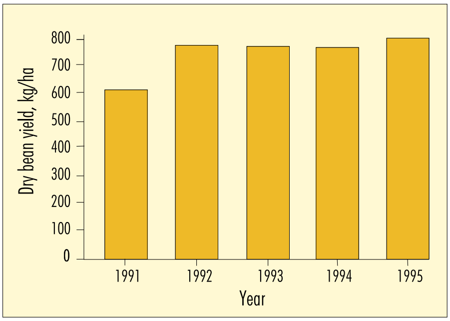
Year of study	pH	OM, %	P, ppm[1]	Al	K	Ca	Mg
				meq/100 g soil			
1	4.6	9.2	10	2.9	0.12	0.60	0.11
3	5.0	9.7	12	2.4	0.21	0.75	0.19
5	5.6	10.8	14	2.1	0.31	1.01	0.26

[1] parts per million

Excellent cocoa production is possible on soils with balanced nutrient content.

Long-term Yield and Profitability Benefits

Average cocoa yields during the five-year period are shown in **Table 2**. The 150-90-200 N-P_2O_5-K_2O treatment produced the greatest response with an average over the five-year period of 1,160 kg dry bean/ha, more than double the yield produced by traditional farmer practice. The typically low nutrient content of these soils (**Table 1**) plus



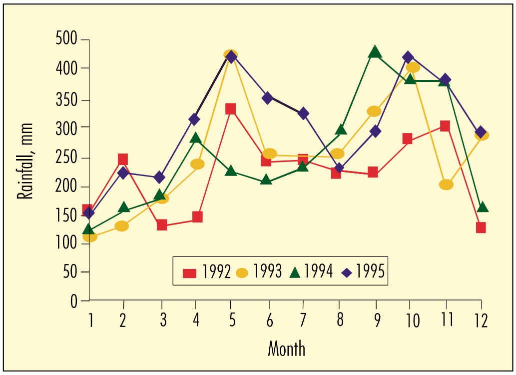


Figure 1. (Left) Average cocoa yields across fertilizer treatments over a five-year period (Santander, Colombia).

Figure 2. (Right) Four-year rainfall distribution pattern in Santander, Colombia.

the large nutrient requirement of the crop demand significant NPK inputs to achieve high yields.

Average yields across fertilizer treatments over the five-year period are shown in **Figure 1**. Highest average yields occurred in year five, 802 kg/ha dry beans. Yields were slightly lower in years two, three and four, and the lowest yield (620 kg/ha) occurred in year one. This suggests that better fertilizer management improves soil fertility and cocoa yields, over time – a phenomenon most likely shared by the majority of plantation crops.

Table 2. Five-year average cocoa yield (Santander, Colombia).

Treatments, kg/ha			Yield of dry beans, kg/ha
N	P_2O_5	K_2O	
Check[1]	–	–	562
50	90	50	560
100	90	50	574
150	90	50	572
50	90	100	601
100	90	100	650
150	90	100	943
50	90	200	819
100	90	200	1,050
150	90	200	1,160

[1] 2 kg of chicken manure. All treatments received 200 g of dolomite per plant.

Most cocoa producing areas of Colombia have an average annual rainfall greater than 2,000 mm. This experimental site averaged 2,960 mm over the last four years of the experiment. Rainfall distribution pattern is an important determinant of fertilizer application timing. Fertilizer split applications should coincide with the initiation of each rainy period (**Figure 2**) because it contributes to fertilizer responsiveness.

A simple economic analysis in **Table 3** considers nutrient input cost against crop value. The most economic treatment was 150-90-200 kg

Table 3. Balanced nutrition effect on cocoa yield and income (Santander, Colombia).

	Treatment					
N	P_2O_5	K_2O	Five-year average yield	Total income	Cost of fertilizer	Net income
- - - - - - - - - - -	kg/ha	- - - - - - - - - - -		- - - - - - - -	US $/ha	- - - - - - - -
Check[1]	–	–	562	289	65	224
50	90	50	560	288	57	231
100	90	50	574	295	74	221
150	90	50	572	294	92	202
50	90	100	601	308	65	243
100	90	100	650	334	83	251
150	90	100	943	484	100	384
50	90	200	819	421	84	337
100	90	200	1,050	538	101	437
150	90	200	1,160	596	117	479

[1] 2 kg of chicken manure. All treatments received 200 g of dolomite per plant.

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N-P_2O_5-K_2O/ha, producing a net profit of US$479/ha, more than doubling income levels compared to common farmer practice.

In K-deficient soils, cocoa production is reduced. Note deficiency symptoms on lower leaves.

Summary

Data obtained in this experiment demonstrate the need of fertilizing full sunlight exposed cocoa plantations. The highest yield was produced with 150 kg of N, 90 kg of P_2O_5 and 200 kg K_2O/ha and affirms that adequate and balanced fertilization of cocoa is not only profitable, but also sustains and builds high yields over time. **BCI**

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Phosphorus Needs of Indian Soils and Crops

By K.N. Tiwari

In 2025 the foodgrain requirement for India's 1.4 billion people will be about 300 million tonnes (M t). This production level will require about 30 M t of nitrogen (N), phosphorus (P), and potassium (K), including 8.6 M t of P_2O_5. In addition, another 14 to 15 M t of NPK would be needed for vegetable, plantation, sugar cane, cotton, oilseed, potato, and other crops. Thus, about 40 to 45 M t of NPK, containing 11 to 13 M t of P_2O_5, will be required just to maintain a broad average $N:P_2O_5:K_2O$ ratio of 4:2:1. This paper further explores P needs of Indian soils and crops.

Phosphorus Fertility Status in India

Based on about 9.6 million soil tests, 49.3 percent of districts and Union Territories are low in available P, 48.8 percent are medium, and 1.9 percent are high (Hasan, 1996). In comparison to an earlier compilation by Ghosh and Hasan (1979), this present survey indicates the low P fertility class has increased by 3.0 percent while medium and high categories have decreased by 2.7 and 0.3 percent, respectively. Both surveys highlight the need for P fertilizer application for proper crop growth in nearly 98 percent of India's districts.

Building the P Status in India's Soils

There are many good reasons why soil P fertility should be built up. High soil P status allows greater flexibility in use of all fertilizer nutrients. Complete crop requirements can be met with smaller annual fertilizer applications. In addition, under difficult economic times, farmers can exercise an option of short-term cutbacks in fertilizer application and possibly incur smaller losses in yield potential.

Utilization of fertilizer P by the first crop to which it is added will range from 15 to 30 percent. However, the balance remaining contributes to residual soil P build-up and is not lost except through erosion or runoff. Good management practices are those that ensure soil fertility status can gradually progress from low to medium to high. Building soil P will:

- Ensure more profitable crop yields over more years. High fertility also helps to reduce the risk associated with crop production.
- High fertility results in more residues remaining after harvest to protect the soil against wind or water erosion, while building

organic matter levels, thereby increasing long-term production potential.

- High P (and K) fertility improves N use efficiency in balanced plant nutrient programs.
- High fertility conserves water by reducing amounts required per unit of crop production.
- Soil P (and K) fertility boosts yield potential, even in weather stress years.
- High fertility interacts positively with other production inputs (i.e., tillage practices, variety, planting date, population) to get the most out of the crop

Phosphorus Consumption Trends in India

Phosphorus consumption in India steadily increased up to 1992. However, the combined government action of removing subsidies on P fertilizer while lowering urea prices effectively reduced national P consumption in 1993-94 (**Table 1**). Phosphorus use recovered slowly, but 1992 consumption levels did not return until 1997-98.

Phosphorus consumption in India increased from 3.92 M t during 1997-98 to 4.10 M t during 1998-99. This increase resulted in a NPK use ratio of 8.5:3.1:1, a step backwards from 7.9:2.9:1 recorded in 1997-98. India's movement towards balanced fertilization is often hampered by greater relative increases in N consumption. Nitrogen consumption increased by 3.9 percent in 1998-99. However, the normal growth rate is closer to 5.0 percent per year. Therefore, had consumption of N maintained its normal growth pattern in 1998-99, the imbalance between N and P would have been even greater.

Perspective on the amount of P consumed in India can be provided through a direct comparison with China. China consumes 2.7 times more P, 2.5 times more N and 2.7 times more K despite having 38 percent less arable land and a similar irrigated cropland area as India. Calculated on arable land basis, in 1997 China applied 188 kg N/ha, 60 kg P_2O_5/ha, and 18 kg K_2O/ha, whereas India applied only 61 kg N, 18 kg P_2O_5, and 6 kg K_2O/ha.

Nutrient use can generally be considered low in India, but P and K use in particular is very low. Average NPK application rates are much lower than usually recommended rates. For example, the recommendation for both rice

Table 1. Consumption of P_2O_5 in India during 1961-99.

	Consumption		Share of total,	$N:P_2O_5$	$P_2O_5:K_2O$
Year	Million t	kg/ha	%	ratio	ratio
1960-61	0.005	0.4	18.0	4.0	1.8
1970-71	0.05	3.3	24.0	2.7	2.3
1980-81	1.21	7.0	22.0	3.0	1.9
1990-91	3.22	17.3	25.7	2.5	2.4
1991-92	3.32	18.2	26.1	2.4	2.4
1992-93	2.84	15.3	23.4	3.0	3.2
1993-94	2.67	14.3	21.6	3.3	2.9
1994-95	2.93	15.6	21.6	3.3	2.6
1995-96	2.90	15.4	20.9	3.4	2.5
1996-97	2.98	16.0	20.8	3.4	2.9
1997-98	3.92	21.0	24.2	2.7	2.9
1998-99	4.10	22.0	24.4	2.7	3.1

and wheat is 120-60-30 kg N-P_2O_5-K_2O/ha.

However, a survey found India's rice received only 87 percent of this P_2O_5 recommendation and 30 percent of the recommended K_2O, while wheat received 65 percent of the recommended P_2O_5 and 17 percent of the recommended K_2O (FAO/IFA/IFDC, 1994). This survey also found a deficiency in N application, as 58 percent of the recommended N rate was applied to rice and only 70 percent to wheat.

This survey compared fertilizer consumption rates for 1992 in China and India and revealed 90 to 100 percent of major crops in China were fertilized with N at rates averaging from 55 to 145 kg/ha. Forty to 90 percent were fertilized with P_2O_5 at rates ranging from 25 to 85 kg/ha. Average K_2O rates varied from 0 to 75 kg/ha. In contrast, India fertilized 47 to 94 percent of the same crops with N, but at much lower rates of 31 to 89 kg/ha.

India applied P and K to a greater percentage of crop area, but much lower rates were used compared to China. Average application rates for P_2O_5 and K_2O ranged from 10 to 50 kg/ha and 2 to 30 kg/ha, respectively. It is clear that fertilizer use in India must be increased to achieve higher yield goals and sustain soil health.

Balance Sheet of Phosphorus

A balance sheet for P in Indian agriculture in 1998-99 is presented in **Table 2.** Using a one-year P use efficiency value of 20 percent, every five units of fertilizer input supplies one unit of plant-available P. The use efficiencies of all other P input sources such as farmyard manure, composts, and crop residues create a net P input far less than the net output resulting from crop removal, animal grazing, and erosion losses.

Table 2. A balance sheet of P in Indian agriculture (illustrative of 1998-99).

	000 tonnes P_2O_5		
Items	Gross	Net	Remarks
INPUT			
1. Fertilizers	4,096	-	Actual consumption
1a. Efficiency (20%)	-	819	20% of 4,096
2. Farmyard manure	655	-	50% of total dung
2a. Efficiency (10%)		66	10% of 655
3. Composts (rural and urban)	1,373	-	Total production (FAI, 1998)
3a. Efficiency (10%)		137	10% of 1,373
4. Crop residues	280	-	5% of total uptake
4a. Efficiency		28	10% of 280
Total Input	6,404	1,050	
OUTPUT			
1. Crop uptake	5,800	-	
Net removal	-	5,200	5% returned through residues
2. Grazing	?	?	Estimates not available
3. Erosion	?	?	Reported to be substantial
Total Output	5,800	5,200	
Balance	+604	-4,200	Excluding erosion and grazing

Phosphorus Removal by Intensive Cropping Systems

Knowledge of nutrient removal under intensive cropping systems is important for development of future P management strategies. Estimates of nutrient uptake for a number of cropping systems in India are provided (**Table 3**).

Table 3. Nutrient uptake in high-intensity and inter-cropped systems in India.

		Nutrient uptake, kg/ha/year			
Cropping system	Yield, t/ha	N	P_2O_5	K_2O	Total
Rice-wheat	8.8	235	92	336	663
Maize-wheat	7.7	220	87	247	554
Pigeonpea-wheat	4.8	219	71	339	629
Rice-rice	6.3	139	88	211	438
Soybean-wheat	7.7	260	85	204	549
Maize-wheat-greengram	8.2	306	62	278	646
Rice-wheat-greengram	11.2	328	69	336	733
Maize-potato-wheat	8.6 + 11.9(t)[1]	268	96	358	722
Rice-wheat-cowpea	9.6 + 3.9(f)	272	153	389	814
Soybean-wheat-potato	3.2 + 6.8(t)	284	41	202	527
Rice-wheat-maize + cowpea	9.3 + 29(f)	305	123	306	734

[1] t and f represent tuber and fodder yield, respectively.
Source: Adopted from Tandon and Sekhon (1988).

Removal of P_2O_5 can reach 150 kg/ha/year (rice-wheat-cowpea fodder), and annual uptake of 75 to 100 kg P_2O_5/ha is quite common under high intensity cropping (i.e., two to three crops/year). Production of 8 to 12 t grain/ha is associated with P uptake of 70 to 120 kg P_2O_5/ha.

Imbalanced Use of Nitrogen Accelerates Depletion of Other Soil Nutrients

Imbalanced application of N (often a result of its relatively low price) neither increases yield nor profit in the long run. But it may result in accelerating deficiency of other nutrients in the soil. Beaton et al. (1993) studied different crop sequences at various locations and found application of N alone increased soil depletion of available P, thus causing fast appearance of P deficiency symptoms (**Table 4**). The same is true for other plant nutrients and is a situation that must be avoided.

Table 4. Depletion of soil by application of N only in intensive cropping.

			kg P_2O_5/ha removed	
Location	Soil	Cropping sequence	Control plot	N-only plot
Barrackpore	Alluvial	Rice-wheat-jute	321	642
Ludhiana	Alluvial	Maize-wheat-cowpea	183	412
New Delhi	Alluvial	P. Millet-wheat-cowpea	160	366
Coimbatore	Black	F. Millet-wheat-cowpea	344	458
Jabalpur	Black	Soybean-wheat-maize	275	366
Hyderabad	Red	Rice-rice	527	847
Bhubaneswar	Laterite	Rice-rice	275	458
Palampur	Hill	Maize-wheat-potato	155	252
Pantnagar	Terai	Rice-wheat-cowpea	893	1,420

Phosphorus Requirement for Meeting India's Food Needs

India's population reached 1 billion in 2000 and is projected to be 1.4 billion by 2025. During 1998-99, India produced 188 M t of cereals and 15.5 M t of pulses. It was estimated that the country will produce 245 M t of food grains during 2001-02 and 285 M t in 2006-07. As food grain production levels increase, fertilizer demand for P (and K) will also increase. The demand for NPK in 2000 and 2005 in India is estimated to be high (**Table 5**).

If India is to bring its current N:P_2O_5:K_2O consumption ratio from 8.9:3.2:1.0 closer to an ideal 2:1.5:1, current P and K consumption must be markedly increased. However, this would still not balance nutrient removal by crops at higher yield targets, and soil P would still be mined.

Table 5. Demand projections of fertilizers (M t) in India by different agencies.

Working group	Year[1]	N	P_2O_5	K_2O
MOA				
	2000	12.8	5.80	2.05
	2005	15.2	7.00	2.40
NIC				
	2000	10.9	4.73	1.94
	2005	12.6	5.61	2.25
PPI				
	2000	13.2	5.88	2.43
	2005	17.8	8.59	4.74

MOA–Sub-working group on fertilizers on 8th Plan projection; NIC-Planning Commission, Government of India; PPIC-India Programme.

Special effort will be needed from the laboratory to the land to balance N and P tonnage and assure crops get the P they need.

Conclusion

Phosphorus deficiency in Indian soils is widespread (98 percent of districts), and crop responses to its application are highly profitable. All indications are that P removal will continue to exceed net P additions, and P deficiency will accentuate further with time. Phosphorus, in fact, must play a much greater role in Indian agriculture than in the past. Profitable cropping with only N is a short-lived phenomenon. Sites initially well supplied with P become deficient with continuous cropping using N alone. Increasing N application without P (and K) application would not be a sound proposition.

Fertilizer rates presently considered as optimum still result in soil nutrient depletion at high productivity levels and, in the process, become sub-optimal rates. There are cases where, in spite of optimum P application, crop yields on low P soils remain lower than yields obtained on high P soils. Also, significant responses to P on high P soils are being recorded from different soil-crop-climatic conditions. Thus, there is urgent need to develop different fertility rating criteria for different soils. The present P fertility limits used in many soil-testing laboratories have outlived their utility. In addition to this, the goal of P research should be to develop methods, products, practices, and programmes which would encourage balanced and efficient use of P in India. **BCI**

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Yellow Pines Signal Potassium Deficiency in Reforested Old Pasture Land in Tasmania

By Philip J. Smethurst, Arthur Lyons, and Keith Churchill

In Tasmania, the development of yellow needles has been observed in some plantations of radiata pine (*Pinus radiata*) established on sites previously used for pasture. An insufficient supply of soil nitrogen (N) or potassium (K) and competition from pasture regrowth were suspected to be causing the deficiency symptoms. Research has shown that a combination of weed control and K application can improve tree colour and increase growth.

Many private forests are being established in Tasmania on land that has previously been used for grazing. Young plantations on some of these sites are developing yellow needles in at least the lower parts of the crown. Deficiencies of N or K were suspected since these nutrients have not traditionally been applied to pastures. Over time, large amounts of both nutrients would have been exported as animal products. Furthermore, plantations established on ex-pasture sites commonly develop a dense sward of grasses and other pasture species. Previous research has shown that pasture species compete strongly with trees for nutrients and soil moisture. Nutrient analysis of foliage showed that nutrient concentrations were similar in yellow and green trees, with the exception of K. Yellow trees had foliar K concentrations of 0.18 percent compared to 0.23 percent in green trees, and both were lower than the published critical concentration of 0.30 percent for radiata pine.

An experiment was undertaken on a two year-old plantation established on land that had previously been pasture. The pines were planted in winter 1997 with good cultivation and weed control using residual granular herbicides to control grass growth. Shortly after planting, the trees were fertilized with N and phosphorus (P). Tree survival at two years was 100 percent. Trees averaged 1.43 m in height, but the sward of pasture had also re-grown. By spring 1999, most trees were yellow to some degree. In December 1999, five replicated treatments were applied to determine the effect of weed control as well as N and K applications on tree growth. The treatments were:

- Control
- Weed removal

- Weed removal with 150 kg N/ha (as urea)
- Weed removal with 120 kg K_2O/ha (as KCl)
- Weed removal with N and K applied as above.

After nine months, all treatments had affected tree colour, foliar K concentration, and tree growth. Weed removal and K fertilization greatly improved the green colour of all trees. Weed control increased the foliar concentration of several nutrients, including N, P, calcium (Ca), and magnesium (Mg), but the extent of increase was greatest for K. Four months after the experiment was started, the concentration of foliar K in control plots was 0.16 percent. Weed removal alone increased foliar K concentration to 0.33 percent, which was above the published critical concentration (**Figure 1**).

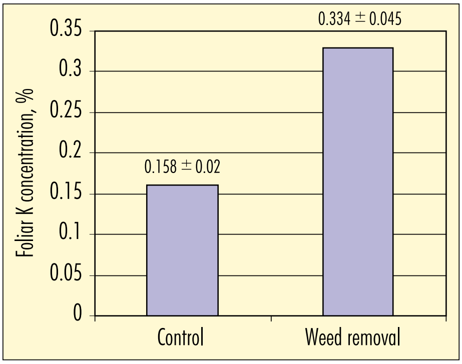


Figure 1. Effect of weed control on foliar K concentration in radiata pine trees (Tasmania).

Tree growth was assessed by indexing the increase in stem volume since the beginning of the experiment. Weed control alone improved tree growth compared to the control. However, where weed control was coupled with K fertilization, tree growth more than doubled (**Figure 2**). Application of N had no measurable effect on tree growth.

Nutrient deficiency also appeared to be exacerbated by drought. During the third year of growth, low rainfall conditions prevailed before the drought broke in winter 2000. Tree yellowing became more severe during the dry period, but decreased after rain (**Figure 3**). In moist soils, K moves to root surfaces largely by diffusion but also by mass flow in the soil solution. Low soil moisture inhibits both processes and thus the amount of K available at the root surface for uptake. Increasing the concentration of K in the soil solution with fertilizer, and therefore the concentration gradient between the bulk soil solution and that at the root surface, can overcome some of the limitations imposed by dry soil.

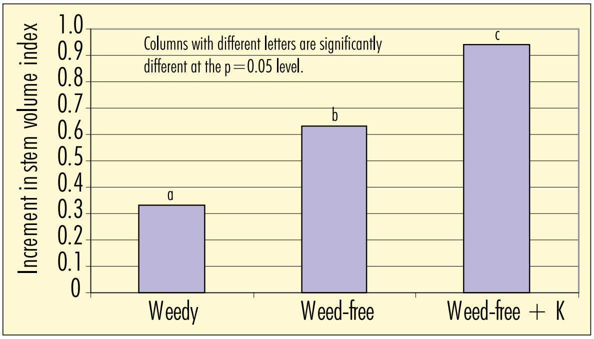


Figure 2. Effect of weed control and K fertilization on radiata pine tree growth (Tasmania).

As a result of this research, guidelines for fertilizing pine plantations on ex-pasture sites in Tasmania include an application of 30 kg K_2O/ha as a spot treatment 15 to 20 cm from the tree four to eight weeks after planting. Additionally, a total application of 115 to 138 kg K_2O/ha over the next four years as 1 to 2 m wide strip applications either side of each row of trees is suggested. Good weed control consists of using knockdown and preferably residual herbicides applied in at least 1 to


Summer 1999 Winter 2000 Summer 2001

Figure 3. The same K deficient tree at ages 2.4, 3.0 and 3.6 years (left to right). This radiata pine tree received no weed control or fertilizer. Yellowing due to K deficiency increased with drought (3.0 yrs.) but decreased when the drought broke (3.6 yrs.), summer 2001.

2 m wide strips along tree rows. Expert advice should be sought to identify sites at risk of K deficiency and to develop site-specific recommendations.

While K deficiency in forest plantations has not been observed in Tasmania previously, it was documented in Gippsland, Victoria, during the 1960s and 1970s where it was also most noticeable on ex-pasture sites. Recently, K deficiency has been suspected in *Eucalyptus globulus* plantations on ex-pasture land in Western Australia. Future work to determine critical leaf K concentrations and growth responses in this species is warranted. **BCI**

Research undertaken by the Cooperative Research Center (CRC) for Sustainable Production Forestry and Commonwealth Scientific and Industrial Research Organisation (CSIRO) Forestry and Forest Products in collaboration with Private Forests Tasmania. Web site: http://www.forestry.crc.org.au E-mail: Philip.Smethurst@ffp.csiro.au

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

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

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

The book can be purchased for US$25 per copy, including shipping/handling. Discounts are available on bulk quantities. For more details, check the website at www.eseap.org, or contact Doris Tan, PPI/PPIC (ESEAP), 126 Watten Estate Road, Singapore 287599. E-mail: dtan@ppi-ppic.org, phone +65 468 1143, or fax +65 467 0416.

Effect of Potash Application on Early Ripening and Yield of Cabbage

By Zhou Yi-min, Huang Feng, Wang Zheng-xiang, and Zhu Jing-hua

Research from northern China has defined the yield and quality benefits farmers can expect from potassium (K) fertilizer application in cabbage...an increasingly important cash crop.

In the Tianjin area, K application promoted early uniform ripening of cabbage.

Due to its cold resistance, short growing time, and rapid biomass accumulation, cabbage has become an important early spring as well as summer vegetable crop grown in north China. The area under cultivation has increased recently. Cabbage is classified as a K loving plant because of its high K requirement. From K fertilization field trials conducted in the Tianjin area of China, it was noted that K application exhibited a significant effect on promoting early uniform ripening and head size as well as increasing cabbage yield.

Effect of K Application on Promoting Early Ripening of Cabbage

Potassium promotes early ripening of cabbage, which allows preferred pricing because of its early entry into the market. It can also increase plant size and form firmer heads than those not receiving adequate K. Based on a harvest of 150 cabbages per treatment plot, data on the early ripening of cabbage are presented (**Figure 1**). Application of 150 to 300 kg K_2O/ha increased early ripening by 82 to 141 percent, about 0.8 to 1.4 times earlier maturing than cabbage not receiving K. An application of 225 kg K_2O/ha resulted in the earliest maturity. Application of 300 kg K_2O/ha produced the latest maturing cabbage among treatments with K added, but this ripening rate was still 82 percent faster compared to the no K treatment.

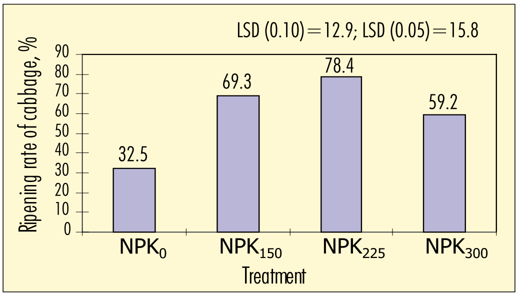


Figure 1. Effect of potash application on early maturing rate of cabbage in Tianjin, China.

Effect of K Application on Above Ground Biomass Accumulation

Cabbage exhibited a marked biomass yield increase with increasing rates of K, in particular with the rate of 225 kg K_2O/ha. This application rate gave the maximum biomass yield increase of 14.2 t/ha (14.4 percent) compared to the no K treatment (**Table 1**). Biomass yield showed

A rate of 225 kg K_2O/ha, with optimum rates of N and P, produced significant increase in cabbage yield.

Table 1. Effect of K application on average gross biomass weight (t/ha) of cabbage in Tianjin, China.

Treatment[1]	Mean gross weight, t/ha[2]	Increase, %
NPK_0	98.8	0
NPK_{150}	105.0	6.3
NPK_{225}	113.0	14.4
NPK_{300}	107.0	8.3

[1] N and P_2O_5 were applied at rates of 225 and 60 kg/ha, respectively, to all treatments.
[2] LSD (0.10)=5.05; LSD (0.05)=6.17

a diminishing trend when additional K (300 kg K_2O/ha) was applied.

Table 2. Effect of K application on cabbage yield and economic benefit, Tianjin, China.

Treatment[1]	Yield, t/ha[2]	Yield increase, %	Cost of fertilizer, Yuan/ha	Net profit, Yuan/ha[3]	Increased income per kg K_2O, Yuan/kg
K_0	49.2	0	1,090	0	0
K_{150}	63.0	28.0	1,400	7,960	53.1
K_{225}	66.6	35.4	1,560	9,970	44.3
K_{300}	58.1	16.1	1,720	4,710	15.7

[1] N and P_2O_5 were applied at rates of 225 and 60 kg/ha, respectively, to all treatments.
[2] LSD (0.05)=9.23; LSD (0.01)=12.8.
[3] Cabbage price=0.6 Yuan/kg, fertilizer price (Yuan/kg): N = 3.5, P_2O_5=5.0, K_2O=2.1

Effect of K Application on Commercial Yield

Potash applied at 225 kg K_2O/ha produced the highest commercial yield increase of 17.4 t/ha (35 percent) compared to no K application. The same rate also resulted in the maximum profit for the farmer of 9,970 Yuan/ha (**Table 2**). This is a clear example of the economic benefit of investing in K for cabbage production in the Tianjin area. At 225 kg K_2O/ha, each Yuan spent on a kg of K_2O provided a gain of 44.3 Yuan.

Eighty plants were sampled from each treatment to study the average gross weight/plant and the commercial weight of big and small classified cabbage. Results indicate the mean gross weight/plant increased by 0.2 to 0.5 kg/plant (**Table 3**). The mean commercial weight of representative large cabbages increased by 0.1 to 0.3 kg/plant. Small cabbages increased by 0.1 to 0.2 kg/plant. Therefore, the effect of K application on increasing cabbage weight applies across all size classes.

Table 3. Effect of K application on cabbage/plant weight (gross kg/plant).

Treatment[1]	Mean gross weight, kg/plant[2]
NPK_0	2.6
NPK_{150}	2.8
NPK_{225}	3.1
NPK_{300}	2.9

[1] N and P_2O_5 were applied at rates of 225 and 60 kg/ha, respectively, to all treatments.
[2] LSD (0.05)=0.30; LSD (0.01)=0.42

Conclusions

Potash applied at the rate of 225 kg K_2O/ha supports rapid heading, rapid maturation, improvements in cabbage quality, and higher farm income. In the Tianjin region, the rate of 225 kg K_2O/ha, along with 225 kg N/ha and 60 kg P_2O_5/ha, is recommended for cabbage production on soils represented by this trial. This application should bring the farmer a net profit of 9,000 to 10,000 Yuan/ha, depending on local market prices. **BCI**

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

Balanced Fertilization on Mango in Southern China

By Zhou Xiuchong, Liu Guojian, Yao Jianwu, Ai Shaoying, and Yao Lixian

The objective of this project was to provide a scientific basis for high yield, high quality and profitable mango production by studying the nutritional characteristics, yield increases, and economic benefits of applying nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and sulfur (S) fertilizers.

Mango is an important tropical fruit, ranking fifth amongst fruit production and consumption worldwide. Normal yields range from 7.5 to 15.0 t/ha. However, in the southern province of Guangdong, yields are low and unstable due to the combined effects of intense climate, poor soil fertility with a spectrum of plant nutrient deficiencies, and a lack of understanding by farmers of the benefits from balanced fertilization. Average mango yield in a Guangdong orchard is only 3.75 t/ha. Fruit quality is poor and less competitive in the global marketplace, resulting in low profits for local mango producers. Sustained profitability in southern China depends on balanced fertilization research in the region.

Experimental Conditions

Trials were conducted in four mango orchards, two each in Shenzhen and Sanshui cities. Test soils were acidic sandy loam, with low available N and deficient levels of available P, K, Mg, S, and zinc (Zn). The eight fertilizer treatments (**Table 1**) were produced using sources available in China (**Table 2**). Since the only available source of Zn was zinc sulfate ($ZnSO_4$) and S was a variable, no application of Zn was made to the treatments.

Table 1. Plant nutrients applied in the different treatments (g/tree/year).

Treatment	N	P_2O_5	K_2O	Mg	S
1. $N_2PSK_1Mg_1$	400	125	320	40	80
2. N_2PSK_1	400	125	320	0	80
3. N_2PSMg_1	400	125	0	40	80
4. $N_2PK_1Mg_1$	400	125	320	40	0
5. $N_2SK_1Mg_1$	400	0	320	40	80
6. $N_1PSK_1Mg_1$	300	125	320	40	80
7. $N_2PSK_2Mg_1$	400	125	440	40	80
8. $N_2PSK_2Mg_2$	400	125	440	80	80

Treatment plot size was 46.8 to 58 m^2, arranged in a randomized complete block design with four replications. Mango trees were seven to nine years old, planted at a density of 855 plants/ha (2.92 m x 4 m). The variety was Zihuaman.

Total fertilizer application rate was split into three applications depending on orchard growth

Table 2. Fertilizers sources and use rates for the different treatments (g/tree/year).

Treatment	Urea	DAP	MOP	SOP[1]	SPM	$MgSO_4$	$MgCl_2$	S^0
1. $N_2PSK_1Mg_1$	763	272	400	0	364	0	0	0
2. N_2PSK_1	763	272	200	444	0	0	0	0
3. N_2PSMg_1	763	272	0	0	0	400	0	29
4. $N_2PK_1Mg_1$	763	272	533	0	0	0	333	0
5. $N_2SK_1Mg_1$	870	0	400	0	364	0	0	0
6. N_1PSK_1Mg	546	272	400	0	364	0	0	0
7. $N_2PSK_2Mg_1$	763	272	600	0	364	0	0	0
8. $N_2PSK_2Mg_2$	763	272	600	0	364	0	333	0

DAP=diammonium phosphate; MOP=muriate of potash; SOP=potassium sulfate; SPM=potassium-magnesium sulfate; $MgSO_4$ =magnesium sulfate; $MgCl_2$ =magnesium chloride.

[1] SOP (made in China) contains 45 percent K_2O and 18 percent S

period (**Table 3**). Fertilizers were applied in small furrows at two opposite sides of each tree; furrows were covered after each application. Fruit was harvested during July 2 to 21.

Plant Nutrient Content and Ratios in Mango Leaf Tissue

Nutrient contents of the most recently matured leaf (MRML) of the fall growth branch are shown in **Table 4**. Under adequate N, P, K, Mg, and S supply, the ranking of plant nutrient leaf contents was N>calcium (Ca)>K>P, Mg and S. The N:P:K:Ca:Mg:S ratio was nearly identical between sites and was 1:0.10:0.60:0.86:0.09:0.09 in Shenzhen and 1:0.09:0.62:0.96:0.09:0.10 in Sanshui.

No significant difference in leaf N content was observed between mango trees receiving 400 and 300 g N/plant. When soil-available P content reached 4.8 to 19.4 parts per million (ppm) there was also no significant difference in leaf P content between the no P application and 125 g P_2O_5/plant. Application of 320 g K_2O/plant increased leaf K content by 0.16 to 0.18 percent over no K application. Application of 40 g Mg/plant increased leaf Mg content by 0.04 to 0.09 percent over no Mg application. Application of 80 g S/plant increased leaf S content by 0.03 to 0.04 percent over no S application.

Table 3. Timing of fertilizer application to mango orchards in Guangdong province.

Growth period	Split application, %	Date
Fall branch promoting fertilizer	40	August 12 to September 11
Flower promoting fertilizer	30	February 24 to March 2
Fruit strengthening fertilizer	30	April 20 to May 17

Table 4. Most recently matured leaf nutrient content for Mango grown in Shenzhen and Sanshui cities, Guangdong province.

	Nutrient content, %					
	N	P	K	Ca	Mg	S
Shenzhen	1.62	0.16	0.98	1.39	0.14	0.14
Sanshui	1.70	0.16	1.05	1.64	0.15	0.17

Table 5. Yield and plant nutrient removal for Mango fruit grown in Shenzhen and Sanshui cities, Guangdong province.

		Plant nutrient uptake in fruit, kg/ha					
	Yield, kg/ha	N	P_2O_5	K_2O	Ca	Mg	S
Shenzhen	13,300	17.7	3.2	25.8	2.6	2.2	1.7
Sanshui	18,700	22.4	3.9	37.1	3.2	3.0	2.3

Plant Nutrient Removal Rate and Ratio with Different Mango Yields

Mango fruit yield and plant nutrient removal by fruit for Shenzhen and Sanshui are shown in **Table 5**. As would be expected, uptake and removal were higher with the higher yield. The ranking of plant nutrient uptake by the fruit was $K_2O>N>P_2O_5>Ca>Mg>S$. It was also noted that while there was more removal with higher yield, the ratio of nutrient removal for the different yield levels was quite similar. Using an average of treatments supplying all nutrients, the $N:P_2O_5:K_2O:Ca:Mg:S$ ratio was 1:0.18:1.46:0.15:0.12:0.10 in Shenzhen and 1:0.17:1.66:0.14:0.13:0.10 in Sanshui.

Table 6. Yield of mango fruit for different treatments at different locations (1997-1999), Guangdong province.

	Average yield, kg/ha				Four trial average yields[1]	
	1998	1999	1997	1998		
Treatment	Shenzhen	Shenzhen	Sanshui	Sanshui	kg/ha	kg/plant
1. $N_2PSK_1Mg_1$	12,800	18,800	9,100	18,200	14,700	17.2
2. N_2PSK_1	11,100	16,200	8,400	13,000	12,200	14.2
3. N_2PSMg_1	9,500	16,500	8,000	13,300	11,800	13.8
4. $N_2PK_1Mg_1$	12,000	16,700	8,300	16,500	13,400	15.7
5. $N_2SK_1Mg_1$	10,800	15,800	9,100	14,700	12,600	14.7
6. $N_1PSK_1Mg_1$	10,300	17,300	8,200	16,700	13,100	15.3
7. $N_2PSK_2Mg_1$	13,200	18,000	9,300	18,800	14,800	17.4
8. $N_2PSK_2Mg_2$	14,000	18,300	9,500	19,000	15,200	17.8

[1] L.S.D. (0.10) = 1,190 kg/ha, L.S.D. (0.05) = 1,440 kg/ha, L.S.D. (0.10) = 1,960 kg/ha.

Effect of Different Plant Nutrients on Mango Fruit Yield, Quality and Profits

Data from both sites show lower fruit yields in the first year, due to excessive rain during flowering. However, by the second year, yields above 18,000 kg/ha were obtained (**Table 6**). Treatment 8 produced the highest four-year average yield of 15,200 kg/ha, with an average of 17.8 kg fruit/tree. However, profit analysis indicated it was not significantly different from treatments 1 or 7, which had similar yields of 14,700 and 14,800 kg/h and 17.2 and 17.4 kg fruit/tree, respectively. Moreover, the quality of mango fruit was equally good for treatments 1, 7 and 8 (data not shown).

Table 7 shows that, subtracting the costs of fertilizers, manpower, pesticides, and rent, growers would realize economic returns of 32,100 Yuan/ha for treatment 8 (ratio of output/input equal to 3.4), while treatments 1 and 7 resulted in returns of 31,300 Yuan/ha.

Since no significant difference in profit could be found among the three best treatments, treatment 1 was deemed the best recommendation because the cost of the fertilizers was lowest at 2,440 Yuan/ha compared with 3,050 Yuan/ha for treatment 8.

Table 7. Profits of different fertilization in mango (1997-1999), Guangdong province.

Treatment	Yield, kg/ha	Cost, Yuan/ha Fertilizer	Other	Output, Yuan/ha	Net profit, Yuan/ha	Value to cost ratio
1. $N_2PSK_1Mg_1$	14,700	2,440	10,500	44,200	31,300	3.4
2. N_2PSK_1	12,200	2,520	10,500	36,500	23,500	2.8
3. N_2PSMg_1	11,800	2,160	10,500	35,500	22,800	2.8
4. $N_2PK_1Mg_1$	13,400	2,560	10,500	40,200	27,100	3.1
5. $N_2SK_1Mg_1$	12,600	2,070	10,500	37,700	25,200	3.0
6. $N_1PSK_1Mg_1$	13,100	2,140	10,500	39,300	26,700	3.1
7. $N_2PSK_2Mg_1$	14,800	2,680	10,500	44,500	31,300	3.4
8. $N_2PSK_1Mg_2$	15,200	3,050	10,500	45,600	32,100	3.4

Note: Fertilizer prices: urea = 1,600 Yuan/t; DAP = 2,200 Yuan/t; MOP = 1,400 Yuan/t; SOP = 1,900 Yuan/t; $MgSO_4$ = 1,600 Yuan/t; $MgCl_2$ = 1,300 Yuan/t; SPM = 1,300 Yuan/t; S = 2,500 Yuan/t. Price of Mango = 3 Yuan/kg.

Effects of Individual Plant Nutrients on Mango

Nitrogen. Application of 300 g N/tree resulted in significantly lower yield and profit than 400 g N/tree. With 400 g N/tree, mango produced 5.7 more fruits per tree, each with a weight increase of 9 g, for a total yield increase of 1,630 kg/ha (12.4 percent). Net profit for 400 g N/tree was 4,600 Yuan/ha, providing growers with good returns. Thus, the appropriate recommendation when other plant nutrients are applied in adequate amounts would be 400 g N/tree/year.

Research in southern China shows the importance of balanced fertilization for sustained yields, quality, and profitability of mango.

Phosphorus. Comparing application of 125 g P_2O_5/tree with no P, trees fertilized with P had 8.1 more fruits per tree, each weighing an average 8 g more per fruit, for a significant yield increase of 2,170 kg/ha (17.3 percent). Net profit increased 6,150 Yuan/ha. Each kg of P_2O_5 produced 20.3 kg fruit. Thus, the proper application rate of P should be 125 g P_2O_5/tree/year.

Potassium. Comparing application of 320 g K_2O/tree with no K application, trees fertilized with K had 10.9 more fruits per tree, weighing 9 g more per fruit, for a significant yield increase of 2,920 kg/ha (24.7 percent). Each kg of K_2O produced 10.7 kg fruit. Net profit increased 8,490 Yuan/ha. Thus, the proper application rate of K should be 320 g K_2O/plant/year.

Magnesium. Comparing application of 40 g Mg/tree to the treatment without Mg showed that mango with Mg applied had 11.1 more fruits per plant, weighing 6 g more per fruit, for a significant yield increase of 2,570 kg/ha (21.1 percent). Each kg of Mg produced 64.3 kg fruit. Net profit increased 7,790 Yuan/ha when Mg was applied. Higher Mg rates gave a slightly higher yield, but no economic benefit. Thus, the proper application rate of Mg should be 40 g Mg/plant/year.

Sulfur. Comparing application of 80 g S/tree to the treatment without S showed that mango with S applied produced 5.5 more fruits per plant, weighing 2 g more per fruit, for a yield increase of 1,340 kg/ha (10.0 percent). Each kg of S produced 19.7 kg fruit. This yield increment was significant at the 0.10 level, indicating a reasonably high probability of increasing yield. Net income increased 4,160 Yuan/ha when S was applied at 80 g/tree. Thus, the proper application rate of S should be 80 g S/plant/year.

Conclusions

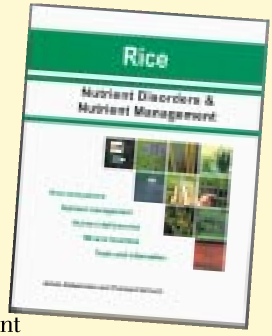
Based on the results of this study, it is recommended that growers use a balanced approach to fertilizer use that includes N, P, K, Mg, and S in the Shenzhen and Sanshui mango growing areas. This balance was achieved by applying urea, DAP, MOP, and SPM. Seventy-five percent of the K was provided by MOP, while the remaining 25 percent of the

New Handbook on Rice Nutrient Management Now Available

The International Rice Research Institute (IRRI) in the Philippines has forecast that rice yields must increase by 30 percent by 2020 to keep pace with growing demand due to population increases.

A new handbook published by IRRI and PPI/PPIC describes site-specific nutrient management methods and provides a reference to assist with the identification and management of nutrient disorders. Titled *Rice: Nutrient Disorders & Nutrient Management*, the 191 page book is authored by Dr. Achim Dobermann, formerly with IRRI and now with the University of Nebraska, and Dr. Thomas H. Fairhurst, Deputy Director, PPI/PPIC East and Southeast Asia Program, Singapore.

Oriented to production in tropical and subtropical regions, topics include rice ecosystems, nutrient management, nutrient deficiencies, and mineral toxicities.


Rice
Nutrient Disorders & Nutrient Management

Estimates of nutrient removal in grain and straw are included to help researchers and extension workers calculate the amount of nutrients lost from the field under various management systems. The publication will improve understanding of new approaches to nutrient management at the farm level.

The book with CD-ROM is available for purchase. The price (including shipping/ handling) is US$32.00 in less developed countries and US$77.00 in highly developed countries. For more details, check the website at **www.eseap.org**, or contact Doris Tan, PPI/PPIC (ESEAP), 126 Watten Estate Road, Singapore 287599. E-mail: dtan@ppi-ppic.org, phone: 65 468 1143, or fax: 65 467 0416.

required K and all Mg and S were supplied by SPM.

Under the conditions of this study, where soil N and P were low to medium and K, Mg and S were deficient, four-year average profitable yields of up to 15,200 kg mango/ha were produced using the following recommendation: 400 g N, 125 g P_2O_5, 320 g K_2O, 40 g Mg, and 80 g S/plant/year.

Nutrient removal of N, P_2O_5, K_2O, Ca, Mg, and S by the fruit from a crop producing 15,000 kg mango/ha was measured at 22.4, 3.9, 37.1, 3.2, 3.0, and 2.3 kg/ha, respectively.

Mango quality was also improved by the recommended application as measured by color, fragrance and taste. Also, fruit weights were higher, with 14 percent solids, 9 percent soluble carbohydrate, 21 mg vitamin C/100 g, and less than 0.3 percent organic acids.The ratio of carbohydrate to acid was 30.

If mango planters follow the above recommendations, they will obtain high yields of good quality fruit, and they will receive higher profits. **BCI**

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Phosphorus Requirements by Garlic under Fertigation

By J.Z. Castellanos, J.L. Ojodeagua, F. Mendez, S. Villalobos-Reyes, V. Badillo, P. Vargas, and I. Lazcano-Ferrat

Fertigation is becoming a very popular practice in irrigated vegetable production. Apart from conserving water, a vital resource, it allows nutrients to be applied with irrigation water where the crop needs it, at the required rate, and at the correct time.

Farmers have increased vegetable crop yields by the effective use of fertigation (Papadopoulos, 1987; Hartz, 1994) mainly developed as micro-irrigation systems. Phosphorus (P) is an important nutrient for successful garlic production. As garlic yield increases, P requirement also increases along with most other nutrients. Application of P to garlic commonly ranges from 50 to 120 kg P_2O_5/ha (Ruiz, 1985), depending on soil P level, crop yield target, and soil characteristics.

There are three basic requirements for maximizing garlic yields under fertigation:

- Soil analysis to define the physical and chemical conditions of the soil and establish the fertilizer and irrigation program.
- Crop nutrient demand data for the growing season.
- Most recently mature leaf (MRML) nutrient concentrations references to correctly interpret the tissue analysis and fine-tune the fertigation program.

Of these three factors, the last two are not adequately defined.

Phosphorus demand by garlic has been reported to range from 50 to 65 kg P_2O_5/ha (Bertoni et al., 1988; Ruiz, 1985). Results of studies have been published in which tissue analysis was used to diagnose P status in this crop. However, they only report P demand for limited stages of the crop's development. They do indicate that the correct P content in the MRML ranges from 0.3 to 0.6 percent P (Jones et al., 1991; Ruíz, 1985; Tyler et al., 1988). Given that garlic is a long season crop (up to seven months), good leaf P status references for the whole season are required. Knowing this information, farmers will have the opportunity to correctly identify deficiencies and, through fertigation, promptly correct them during any growth stage.

Garlic grown under fertigation has a higher yield potential and P uptake.

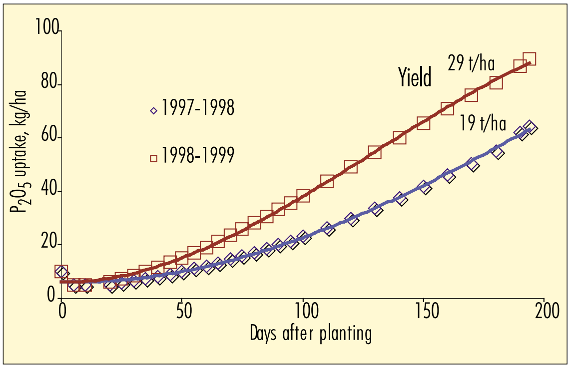


Figure 1. Phosphorus uptake by garlic under furrow irrigation (1997-98) and fertigation (1998-99) in a Vertisol (central Mexico).

Experimental Conditions

The study was conducted on a Vertisol with a pH of 7.8, 2.1 percent organic matter, 14 parts per million (ppm) Olsen P, 18.1 $cmol_c$/kg calcium (Ca), 5 $cmol_c$/kg magnesium (Mg), 2.8 $cmol_c$/kg potassium (K), 5.7 ppm DTPA iron (Fe), 0.8 ppm DTPA copper (Cu), 1.2 ppm of DTPA zinc (Zn), and 12 ppm DTPA manganese (Mn). Work was conducted at the Celaya Agricultural Research Station of the National Institute of Agricultural Research (INIFAP). The station is located in central Mexico at 20° 15´ N latitude, 101° 39´ W longitude, and 1,650 m above sea level, with an annual average temperature of 19°C.

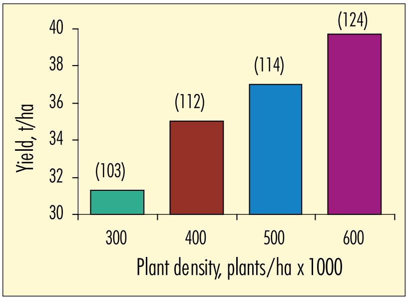
The study used furrow irrigation in 1997 and 1998 and fertigation in 1998 and 1999. Phosphorus uptake curves were obtained for these two experiments. Another fertigation experiment was established in 1999 and 2000 to explore the effect of plant density on yield and crop P uptake. Garlic received 80 kg of P_2O_5/ha at planting in all experiments and 240 and 285 kg of nitrogen (N)/ha in 1996 and 1997, respectively. The plant density experiment in 1999 and 2000 used 405 kg N/ha. In 1997 and 1998, N was split using three applications during the season. In both fertigation experiments, N fertilizer was applied as demanded by the crop via irrigation water. All three experiments received 100 kg K_2O/ha. Plant density was 300,000 plants/ha for the furrow-irrigated experiment and 380,000 plants/ha for the fertigated experiment in 1998 and 1999. Four plant densities of 300,000, 400,000, 500,000, and 600,000 plants/ha were studied in 1999 and 2000. In all cases, the cultivar was *cv.* Tacascuaro.

Phosphorus Extraction Data for Garlic

Figure 1 shows season-long P uptake data by garlic for different experimental irrigation schemes. The garlic crop takes up very little P during the first 50 days after planting, but uptake greatly increases after that date. Garlic grown under furrow irrigation took up 64 kg P_2O_5/ha, while under fertigation the crop took up 89 kg P_2O_5/ha. The respective crop yields were 19.1 and 29 t/ha. Thus, higher yield potential of the crop under fertigation increased P demand by the plant by almost 50 percent. These data show that each tonne of garlic removes as much as 3.1 to 3.6 kg P_2O_5.

As shown in **Figure 2**, garlic yield increased as plant density increased. Yield increased from 31 t/ha with 300,000 plants/ha to 39.7 t/ha with 600,000 plants/ha. Planting density is an important factor when

Figure 2. Yield of bulb and P uptake (kg P_2O_5/ha) by garlic under fertigation and grown at four different population densities (central Mexico).



considering P uptake. Based on these data, P uptake increased from 103 to 124 kg of P_2O_5/ha for the respective yields. These outstanding yields are not reported in the literature.

Unfortunately, bulb size was reduced as yield increased, a quality factor that negatively affects fresh market value. For industrial purposes, small bulb size is not critical, but a plant density of 300,000 plants/ha would be better for garlic grown for fresh markets.

Proper Sampling of the MRML for P Content

Table 1 shows adequate P content ranges for MRML of garlic for several stages of the growing season. It is common that adequate P levels for the MRML decline as the plant ages. It should also be noted that leaf position on the plant also affects P content measurements. Hence, it is important to use the MRML for tissue P analysis. As shown for the two sampling dates presented in **Figure 3**, regardless of crop age, the younger leaf will have higher P concentrations. In **Table 1**, the MRML corresponds approximately to leaf number 4 (**Figure 3**), which is found by counting back from the most immature leaf to the most recently mature leaf. The correct MRML is commonly identified as having formed a ring around the base of its stem. **BCI**

Table 1. Phosphorus content in the most recently mature leaves for different growth stages of garlic (Celaya, Gto., Mexico).

Days after planting	Growth stage	Leaf P, %
22	V-3	0.40-0.50
29	V-4	0.30-0.40
35	V-5	0.30-0.35
49	V-7	0.25-0.35
63	V-9	0.25-0.35
78	V-11	0.25-0.35
94	V-13	0.25-0.35
107	IBG	0.25-0.35
122	IBS	0.25-0.30
147	BG	0.20-0.30

V=vegetative stage (number of leaves);
IBG=initiation of bulb growth;
IBS=initiation of bulb splitting;
BG=bulb growth

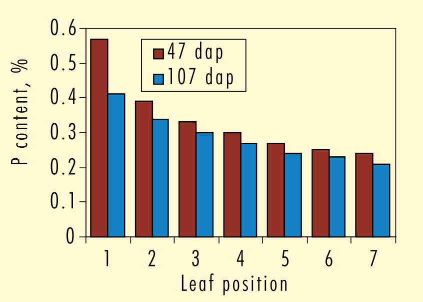


Figure 3. Effect of leaf position on P content in the MRML of garlic crop at 47 and 107 days after planting (dap); central Mexico.

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The Changing Face of Balanced Fertilizer Use in India

By K.N. Tiwari

For India, there is an urgent need to narrow the wide ratio between nitrogen (N) and phosphorus (P) and potassium (K) consumption by stepping up P and K usage, which suffered markedly during much of the 1990s. By doing so, food security will be safeguarded and agricultural practices will be more sustainable. India would need about 25 million tonnes (M t) of NPK in addition to 10 M t of organic and biofertilizer sources to produce about 246 M t of foodgrain required by 2010.

India's introduction to fertilizer-responsive, high-yielding varieties (HYV) of rice and wheat during the 1960s made it possible to produce 15 to 20 tonnes of plant biomass (dry matter) per hectare per year. This productivity could be initially maintained with N fertilizer alone as the soil could provide much of the other nutrients needed by the crop. However, within a few years, the soil reserves of many nutrients were gradually exhausted, and high yields were no longer possible by applying N alone. Therefore, a growing emergence of plant nutrient deficiencies occurred in areas of increasing crop intensity.

During 1998-99, consumption of N, P_2O_5 and K_2O in India was 11.3, 4.1 and 1.33 M t, respectively at 90 kg/ha. A sustained, imbalanced use of nutrients is reflected by the $N:P_2O_5:K_2O$ ratio which widened from 5.9:2.4:1 in 1991-92 to 8.5:3.1:1 in 1998-99 (**Table 1**).

Table 1. Trends in nutrient consumption and use ratio, India.

	$N-P_2O_5-K_2O$ consumption,	Consumption ratio	
Year	kg/ha	$N:P_2O_5:K_2O$	$N:P_2O_5$
1991-92	69.8	5.9: 2.4: 1	2.4: 1
1992-93	65.5	9.5: 3.2: 1	3.0: 1
1993-94	66.3	9.7: 2.9: 1	3.3: 1
1994-95	72.1	8.5: 2.6: 1	3.3: 1
1995-96	74.4	8.5: 2.5: 1	3.4: 1
1996-97	76.7	10.0: 2.9: 1	3.4: 1
1997-98	86.8	7.9: 2.9: 1	2.7: 1
1998-99	90.0	8.5: 3.1: 1	2.7: 1
Overall desired norm		4: 2: 1	2: 1

If the nutrient consumption pattern in 1998-99 equaled the desired 4:2:1 ratio, the 11.32 M t of N would be matched with 5.66 million P_2O_5 tonnes (38 percent more than actual) and 2.83 million K_2O tonnes (over twice actual K_2O consumption). The challenge for government and industry alike is to meet or exceed this consumption level.

Long-term Experiments Emphasize Balanced Fertilizer Use

Findings from long-term fertilizer experiments have clearly shown how the high productivity of an N-driven system is short-lived and counter-productive. Continuous use of N alone can never produce sustained, high yields without addition of adequate

Table 2. Response to N, P and K over years in a rice-wheat cropping sequence on alluvial soils at Faizabad, Uttar Pradesh, India.

Crop	Period	Control yield, kg/ha	Response, kg/ha[1] N (120)	P_2O_5 (80)	K_2O (40)
Rice	1977-78	1,010	2,905	500	50
	1989-90	820	2,640	925	231
	Change	-190	-265	+425	+181
Wheat	1977-78	833	2,625	617	25
	1989-90	602	2,140	1,170	398
	Change	-231	-485	+553	+373

Source: Project Directorate of Cropping Systems Research, ICAR, Modipuram, Uttar Pradesh.

[1] Numbers in parentheses represent nutrient rates per hectare.

P, K and other deficient plant nutrients. This can be verified by the relatively higher P and K fertilizer use efficiencies and relatively lower N use efficiency in India during the 1980s and 1990s as compared to the 1970s (**Tables 2** and **3**).

The Dynamic Nature of Balanced Fertilization

A wealth of information on the dynamic nature of balanced fertilization in intensive cropping systems has become available from several long-term fertilizer experiments in which HYVs are grown. Results consistently show: 1) intensive cropping with only N input is a short-lived phenomenon; 2) omission of a plant nutrient (be it macro or micro) leads to its progressive deficiency as a result of heavy removals; 3) sites initially well supplied with natural soil P, K or sulfur (S) become deficient when continuously cropped using N alone or S-free fertilizers; 4) fertilizer rates considered as optimum still resulted in nutrient depletion at high productivity levels and, if continued, become sub-optimal rates.

More than anything else, these experiments solidly demonstrated that a field producing 1,300 kg grain/ha from two crops grown without fertilizer could produce 7,420 kg grain (5.7 times more) under optimum plant nutrient application (data not shown). Responses to fertilizers in these experiments were always in the order of NPK>NP>N. Continuous use of N alone produced the greatest yield decline at a majority of sites. Responses to N declined with the passage of time, while responses to P and K improved due to increased soil P and K deficiency (**Table 3**).

Table 3. Nutrient response ratio (kg grain/kg nutrient) in long-term fertilizer experiments: 1973-77 vs. 1992-96, India.

Location, soil and crops	Nitrogen 1973-77	Nitrogen 1992-96	Phosphorus 1973-77	Phosphorus 1992-96	Potassium 1973-77	Potassium 1992-96
Palampur (Alfisol)						
Maize	14.6	-1.6	13.9	20.6	2.4	20.0
Wheat	4.3	-3.1	13.4	21.2	3.6	13.2
Ranchi (Alfisol)						
Soybean	-10.4	-8.1	6.1	10.6	4.1	20.6
Wheat	-7.8	-1.4	29.9	38.2	1.0	15.9
Coimbatore (Inceptisol)						
Finger millet	3.1	5.4	35.3	43.9	-11.4	13.4
Maize	1.7	-1.3	32.7	28.6	-1.3	14.5
Bhubaneshwar (Inceptisol)						
Rice (kharif)	6.7	2.6	-1.05	5.5	6.9	8.2
Rice (rabi)	11.2	3.2	1.8	14.1	2.7	5.5
Jabalpur (Vertisol)						
Soybean	26.0	8.4	7.9	7.7	2.9	13.7
Wheat	7.0	0.5	20.2	41.1	8.4	6.0

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

Data such as those in **Table 3** are not just pieces of academic information because they clearly point out the disastrous consequences of practicing intensive farming without due attention to balanced fertilization. Taking the case of maize at Palampur, during 1973-77 each unit of N applied produced 14.6 kg grain while each unit of K produced 2.4 kg grain. About two decades later (1992-96) in the same field, the maize response rate to N dropped from 14.6 to -1.6 while that to K increased from 2.4 to 20 kg grain/kg K_2O. The response to N dropped because other plant nutrients (i.e., P, K) became deficient, preventing the full benefit of N. The response to P and K increased over time because of the depletion of soil P and K reserves, which made fertilizer application essential for high yields. As a result, use of N alone became a losing proposition while that of P and K became more attractive and profitable. At Ranchi, use of N alone always resulted in negative responses and monetary losses because the experimental soils were highly P deficient.

These are some eye-opening examples of the disastrous agro-economic consequences of unbalanced (N-dominated) fertilization. Adoption of a balanced approach right from the beginning will safeguard higher returns from money spent not only on plant nutrients, but also other input costs and farming enterprise as a whole.

Optimum Rates Change with Yield Goals

Results of long-term experiments also reveal that the conventionally considered optimum application rates can in reality be sub-optimal and not capable of producing the highest yield potential (**Table 4**).

Evidently, normally recommended rates of NPK fertilizers are sub-optimal in intensive cropping systems in several cases. Maximum yield research data initiated by the PPIC–India Programme revealed that it is possible to surpass the national demonstration yield level by a considerable margin both in a rice-rice system (Tamil Nadu) and rice-wheat system (Punjab, Uttar Pradesh) by applying higher NPK rates and adopting improved production technology. This implies that higher nutrient depletion demands a higher rate of nutrient replenishment to safeguard the soil fertility balance.

Table 4. The sub-optimal status of optimum NPK application rates in wheat, India.

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

Source: Nambiar, K.K.M. (1994) ICAR-AICRP long-term fertilizer experiments.

Balanced Fertilization Includes Nutrients Other than NPK

Balanced fertilizer use today in India implies much more than NPK application. Almost 50 percent of over 200,000 soil samples analyzed have tested low (deficient) in zinc (Zn). Soil S deficiencies once considered to be confined to coarse-textured soils under oilseeds are now estimated to occur in a wide variety of soils in nearly 130 districts, and yield increases from application of S under field conditions have been recorded in over 40 crops. Likewise, in specific areas, the application of magnesium (Mg) and boron (B) has become necessary for high yields, greater plant nutrient use efficiency, and enhanced profits. These nutrient combinations represent the many facets of balanced fertilizer use (**Table 5**).

Table 5. Balanced nutrient application for a number of soil/crop combinations in India.

No.	Situation	Component of Balance
1.	Many alluvial soils, wheat belt	N, P, K, Zn, and S
2.	Red and lateritic soils	N, P, K, with lime
3.	Many areas under oilseeds	N, P, K, S, and B
4.	Malnad area of Karnataka	N, P, K, S, and Mg
5.	High yielding tea in South	N, P, K, Mg, S, and Zn

Therefore, feeding crops for high yields in India is no longer a simple NPK story. This in no way minimizes the importance of NPK (fertilizer pillars), but emphasizes that the efficiency of NPK and returns from their application can be maximized only when due attention is paid to other plant nutrient deficiencies.

In conclusion, Indian agriculture is now in an era of multiple plant nutrient deficiencies. At least five nutrients (N, P, K, S, and Zn) are now of widespread practical importance from an application point of view. It would not be surprising if progressive farmers in several areas must apply four to six nutrients to sustain high yields of premium crops. Policies and strategies need to be developed to fully recognize the changing needs and dynamics of balanced fertilization. Towards this end, policy-makers, researchers, extension personnel, fertilizer industry, dealers, and farmers all have to contribute. **BCI**

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Dr. Tiwari is shown inspecting a bean crop grown with balanced fertilization in India.

*“Knowledge comes,
but wisdom lingers”*
—Tennyson

I like the thought this statement conveys. It rings true to what we try to accomplish at PPI/PPIC in concert with our cooperators around the world. In past back cover notes, I have invariably written about the need for science-based information and that when integrated with other **information** it becomes **knowledge** and **technology**. All very practical. However, as I meet farmers and planters throughout the world, I am struck by the **wisdom that has lingered.**

But wisdom is borne of experience and foremost is the wisdom to survive economic and climatic calamities. Survival has been the traditional form for sustaining agriculture. What too many of the world’s farmers haven’t experienced, and therefore omit from their fundamental wisdom, is the new knowledge that strengthens their capability and gives them a greater insight into the wisdom that truly sustains agriculture.

Through *Better Crops International* and the programs which the Institute supports, we seek to work at the leading edge of wisdom by first getting new information and secondly by explaining what the information means and how farmers can use it. **Wisdom lingers** when supported by the truth—the basis of science. **Wisdom lingers** when its fundamental basis is fitted, through the application of new scientific information, to contemporary factors of agronomic, economic, and environmental needs. **Wisdom lingers** when the women and men of agriculture are given new tools for sustaining agriculture—to ensure food security, environmental protection, and economic prosperity.

Knowledge must come so that wisdom can linger.

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and President, PPIC

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