

# LEAF ANALYSIS AND SOIL TESTING FOR PLANTATION TREE CROPS

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## ABSTRACT

*The Bulletin reviews the information on the use of leaf analysis and soil testing for plantation tree crops such as rubber, oil palm, cocoa, and coconut, with an emphasis on Malaysia's experience. In addition, critical levels of nutrient elements in leaf tissues for these crops are reported. This is accompanied by a discussion on the combined use of soil testing and leaf analysis to assess nutrient needs and fertilizer rates.*

## INTRODUCTION

Plant tissues, particularly leaves, are analyzed to determine the nutrient content in the sample and hence in the selected stand of the crop, with a view to utilizing the data to improve fertilizer use efficiency and/or to confirm visual symptoms. The potential role of leaf analysis in fertilizer use includes evaluation of the rates of nutrient inputs needed; checking on nutrient deficiencies and any imbalance, interaction or antagonisms; and determination of whether the fertilizers applied are being utilized by the plants. Basically however, leaf analysis indicates the nutritional status of the crop at the time of sampling.

Soil analysis, on the other hand, has the advantage that it can measure the level of immediately available nutrients in the soil (nutrient intensity), and the soil's ability to continue the supply of nutrients throughout crop growth (nutrient capacity). Interpretation of soil analysis allows for assessing fertilizer needs, but it does not allow us to evaluate the efficiency or sufficiency of nutrient uptake to ensure optimal growth and productivity of the crop(s).

Working with rubber (*Hevea brasiliensis*) in Malaysia, Pushparajah and Guha (1968) showed that the response to fertilizers, and thus the nutrient needs, varied not only with leaf nutrient content, but

also according to soil type and the nutrient content of the soil. They also showed that where the soils of the trial sites had been well characterized and the trials well monitored, the results of a limited number of trials could be used elsewhere on similar soils. Such adoption is based on relationships of yield to soil parameters and plant tissue analysis. Fertilizer use has been developed on this basis in Malaysia in particular, not only for rubber but for other plantation crops. Diagnostic criteria with varying levels of confidence for application to different perennial tree crops are now available. As a consequence, many government agricultural institutions and a number of commercial ones in Southeast Asia have set up their own facilities for field sampling and observation, for soil and leaf analysis, and eventually for calculating fertilizer recommendations for perennial tree crops. This paper deals with the current status of use of leaf analysis and soil testing for assessment of the specific nutritional needs of plantation tree crops.

## FACTORS INFLUENCING LEAF NUTRIENT CONTENT

Pushparajah and Chew (1979) in their review showed that, at least for rubber and oil palm, there was sound evidence that the nutrient levels in leaf tissues were influenced by many factors other than inherent factors of soil. These additional factors

Keywords: critical nutrient content, fertilizer rates, leaf analysis, nutrient requirements, plantation crops, sampling intensities, soil testing

include:

- modifying factors through the soil;
  - fertilizer inputs,
  - type of vegetation cover; e.g. with legume cover there could be higher N, etc.,
- position of leaf tissue within the canopy;
- factors inherent in the tree;
  - genetic make-up,
  - age of crop,
- time of sampling;
  - yearly (seasonal) variation,
  - age of leaves,
- yield of crop (and hence nutrients drained from the system).

The effect of soil and modifying factors through soil are readily appreciated, and needs no elaboration. However, other factors do need some discussion.

### **Position of Leaf Tissue**

There is considerable variation in the nutrient content of leaves related to their position in the canopy. This variation is influenced by the intensity of exposure to the sun's radiation and in some instances (e.g. in oil palm for which leaves are selected according to their position on the stem) on the age of the tissue. In order to minimize variation, the type of leaf and/or the position of leaves from mature plants to be selected have been identified for use in Malaysia as follows:

- Rubber - Basal leaves of top whorl of shoots of branches in shade of canopy,
- Cocoa- Third or fourth leaf of the last maturing flush,
- Coffee- Third or fourth pairs of leaves from tips of fruit-bearing branches at mid-height of tree,
- Coconut - Leaf 14,
- Oil palm - Leaf 17,
- Mango - Fifth leaf from base of current flush after harvest.

### **Genetic Variation**

Pushparajah and Chew (1979) in their review have shown that the genetic make-up of the crop influences the nutrient content of rubber and oil palm, and the nutrient needs of rubber. Magat (1992) in his review showed that there were minor

difference between varieties of coconut (local tall varieties, dwarf varieties, and hybrids). Nevertheless, they showed a common pattern in that nutrient requirements were related to yield (Chew 1982).

Nutrient content also varies with the age of the tree. However, after canopy closure (three to six years after field planting) variation according to the age of the tree is often less.

### **Time of Sampling**

Choosing a different time for sampling leaves of e.g. rubber can mean that the samples contain leaves of a different age. Pushparajah and Tan (1972) working with rubber showed that the optimum leaf age for interpretation of nutrient status was around 100 days. However, sampling could occur from around 90 to 160 days after leaf formation. They found a relationship between leaf calcium levels and leaf age, and introduced correction factors for leaf age based on leaf and soil Ca values. Iyer *et al.* (1980) computerized the adjustments of leaf nutrient status to correspond to those at optimum leaf age.

A more insidious variation is one due to seasonality. In rubber, Pushparajah and Tan (1972) showed that the year-to-year variation (even after correcting for leaf age) was quite large, even in plots which had not been given fertilizer, and could cover the range from deficiency to sufficiency. In oil palm, too, seasonal and yearly variation in the nutrient contents in leaves has been found to be large (Foster and Chang 1977). Thus, when leaf analysis from commercial plantations in any one year is being interpreted, reference must be made to the analysis of leaves from control plots (Pushparajah 1977).

### **SOIL ANALYSIS**

Pushparajah (1977) reviewed the use of soil analysis for rubber, and showed that researchers had established relationships between the trees' performance and total N,  $\text{NH}_4\text{F}/\text{HCl}$  extractable P (Bray II), sulphuric/perchloric acid extractable P, 6N HCl extractable K and Mg in the soil. Thus these soil indicators are generally monitored for rubber. The same extraction procedures seem to be appropriate for other plantation crops such as oil palm, cocoa, and coconuts in Malaysia (Pushparajah and Chew 1979, Sompongse and Pushparajah 1994).

## SAMPLING INTENSITIES FOR COMMERCIAL FIELD

### Soil Samples

Chang *et al.* (1977) showed the need to consider both pedogenetic-induced variability and management-induced (fertilizer input) variability of soils in a field. Their work showed that when planted in rubber, a soil derived from granite (Rengam series, a Typic Paleudult) was less variable than a soil derived from shale (Munchong series, a Tropeptic Haplorthox). Thus for example a field soil sampling unit in Typic Paleudult soil could be 20 to 30 ha per bulked soil samples, but for the Haplorthox, for 10% precision, the sample size had to be about 10 ha. Thus a general appreciation/evaluation of the heterogeneity of soil types should be used as a guide to determining sample size. For convenience, the size of the field used for leaf sampling follows that used for soil sampling.

Sampling of individual fields based on soil type and planting material for use in assessing fertilizer requirements is feasible in the case of estates (plantations), and smallholdings in organized schemes, since available records allow us to evaluate the management history. However for individual smallholdings under rubber, since access is often difficult and there are no records of the management history, a different approach is used.

Soils under rubber in Malaysia have been mapped at the reconnaissance level. This was done initially by super-imposition and interpretation of land use maps, reconnaissance soil maps and air photos, all subsequently verified by field checking. On the basis of these maps, the more common soil series/associations were identified. Fertilizer trials on sites selected to represent the common soils show how important these were in ensuring that fertilizers gave an economic return (Pushparajah *et al.* 1973). The subsequent grouping of rubber areas according to their soil type, a knowledge of soils, and assessment of the nutritional status of leaves from stratified samples, has made possible the formulation of fertilizer schedules by soil types for individual smallholders (Chan *et al.* 1972).

### Leaf Samples

Generally, leaves are sampled from about 30 trees in each sample field. The samples are then pooled, and then often sub-sampled in the laboratory prior to drying and preparation for analysis. The size of sample field often follows the size used for soil

sampling.

## UTILIZATION OF SOIL AND LEAF ANALYSIS

The relationship between leaf analysis and plant productivity is generally evident for most crops, and an assessment of fertilizer needs can be based on such an analysis. However for a cost-effective approach, leaf analysis has to be integrated with soil analysis. This is because there may be instances where plant uptake of nutrients present in adequate amounts in the soil may be inhibited by the lack of another limiting element, e.g. uptake of K can be reduced by the lack of N. In a case of this kind, leaf analysis will reflect the need for N and K fertilizer. Reference to soil analysis will indicate that the K reserves in the soil are adequate and thus K fertilizers need not be used. This allows a savings in the cost of inputs.

In addition to the above, Pushparajah and Chew (1979) emphasized that to obtain best results, all analytical data available must be used together with other criteria, in particular the environment and growing conditions (soil type, slope, rainfall, soil cover etc.), physiology of growth and productivity, yield, nutrient requirements of the crop, and experimental data from fertilizer trials. The uptake (immobilized in the growing trees, exported when the harvested crop or its by-products are removed, or returned to the soil when residues are recycled) features prominently in the assessment of actual needs. Data on uptake by most perennial and other crops are readily available (IFA 1992). A review of nutrient uptake by rubber, oil palm, cocoa and coconuts has been published recently (Pushparajah and Chew 1994).

Up to the present, the integrated use of soil and leaf analysis on an extensive scale has only been used for rubber in Malaysia. For other crops, soil analysis is often used to monitor a build-up of nutrients, particularly P, to monitor long-term trends, and to detect possible imbalances. The approaches used for rubber are dealt with in greater detail below. Most of the data referred to is from work carried out in Malaysia.

### Rubber

The first step was to category levels of nutrients into groups (Pushparajah and Tan 1972) and to define levels of deficiency, sufficiency and excess (Table 1).

Later, Pushparajah (1977) categorized the

level of nutrients in soil according to availability classes (Table 2). These nutrient levels give an indication of the likelihood of a response, although the actual levels can change over time.

At the same time, data interpretation to assess actual nutrient needs was standardized, and the requirements for fertilizer rates according to soil and foliar analysis defined (Pushparajah 1977). This tabulation (Table 3) provides a sample of the development which has made possible a computerized approach to interpretations of soil and leaf data (Table 4) The rates are for areas yielding 1500 kg ha<sup>-1</sup> y<sup>-1</sup> of dry rubber. Methods to calculate the additional fertilizer needed for areas yielding above this level have also been developed.

Though these levels are generally used, Foster and Goh (1977) have suggested the need for different critical levels for inland soils (mainly "low activity clay", consisting of soils such as Oxisols and Ultisols), and for coastal soils (mainly soils with 2:1 lattice clays e.g. Inceptisols). The critical range for the nutrients N, P, and K given below reflect the

differences for the two major soil groupings (Table 5).

Some years later, Foster *et al.* (1985) could demonstrate a relationship between soil properties including drainage, yield level, plant age and plant density, and response to fertilizers. On the basis of these relationships, they formulated equations which allow the estimation of N and K fertilizer requirements of oil palm. However, these equations are not widely used in Malaysia.

## Coconut

Soil analysis to assess the fertilizer needs of coconut is not fully developed. Generally, there is a dependence on leaf analysis, especially frond 14 of mature palms (Chew 1982; Magat 1992). The optimum range of the nutrients and fertilizer rates vary with the variety (Table 6), and thus there is a need to identify the genetic make-up of a given stand of palms.

Table 1. Range of nutrient contents in rubber leaves at an optimum age, and under shade from the canopy

Nutrient	Nutrient level category*			
	Low	Medium	High	Very high
% in dry matter				
N group 1**	< 3.2	3.21 - 3.50	3.51 - 3.70	> 3.71
2	< 3.3	3.31 - 3.70	3.71 - 3.90	> 3.91
3	< 2.9	2.91 - 3.20	3.21 - 3.40	> 3.41
P	< 0.19	0.20 - 0.25	0.26 - 0.28	> 0.28
K group I**	< 1.25	1.25 - 1.50	1.50 - 1.65	> 1.70
II**	< 1.35	1.35 - 1.65	1.65 - 1.85	> 1.90
Mg	< 0.2	0.20 - 0.25	0.26 - 0.30	> 0.30
ppm in dry matter				
Mn	< 45	45 - 150	151 - 300	> 300 > 500 = toxic

Source: Pushparajah and Tan (1972)

Note: \* Low = Tending to produces visual signs of deficiency  
 Medium = Sub-optimal level  
 high = Levels above which any response is unlikely  
 Very high = Imbalance with other nutrients likely

\*\* Group I = All clones except those in groups 2 and 3  
 Group 2 = RRIM 6000, GT1 and other clones with similar characteristics  
 Group 3 = Clones susceptible to trunk snap  
 Group I = All clones except those in Group II.  
 Group II = RRim 600, GT1, most PB clones and progenies.

Table 2. Characterization of potential nutrient availability or supply (soil depth 0-30)

Parameter	Nutrient level category*			
	Low	Medium	High	Very high
C (%)	0.50	0.51 - 1.50	1.51 - 2.50	> 2.6
N (%)	< 0.10	0.11 - 0.20	0.21 - 0.40	> 0.41
P (mg kg <sup>-1</sup> )				
- Sulphuric/perchloric extr.	< 250	251 - 350	351 - 600	> 600
- Bray II extr.	< 11	11 - 20	21 - 30	> 31
K (c mol kg <sup>-1</sup> )				
-6N HCl extr.	< 0.5	0.51 - 2.0	2.1 - 4.0	> 4.1
Mg (c mol kg <sup>-1</sup> )				
- 6 N HCl extr.	< 0.75	0.8 - 3.0	3.1 - 8.0	> 8.1

Source: After Pushparajah (1977)

\* Low/medium = Deficiency to be expected

High/very high = Soil reserves adequate but there is a need to monitor for imbalances with other nutrients, especially at the very high level.

Table 3. Nutrient needs according to soil and leaf nutrient status

a. Nitrogen needs (g/tree <sup>-1</sup> y <sup>-1</sup> )						
Leaf N (%)	Soil N and clone group*					
	Soil N < 0.10%			Soil N 0.11 - 0.20%		
	I	II	III	I	II	III
2.8 - 3.0	500	650	150	400	550	200
3.0 - 3.2	350	520	100	270	420	80
3.2 - 3.4	200	350	50	140	300	-
3.4 - 3.6	100	200	-	50	180	-
3.6 - 3.8	70	100	-	50	50	-
3.8 - 4.0	-	70	-	-	-	-

  

b. Potassium needs (g/K <sub>2</sub> O/tree-1 y-1)				
Leaf K(%)	Soil K and clone group*			
	6N HCl ext. K < 0.5 c mol kg <sup>-1</sup>		6N HCl ext. K > 0.5-1.0 c mol kg <sup>-1</sup>	
	I	II	I	II
0.8 - 1.0	1400	1900	1150	1500
1.0 - 1.2	1000	1400	700	1100
1.2 - 1.4	650	100	400	600
1.4 - 1.6	350	650	150	350
1.6 - 1.8	200	400	-	9200
1.8 - 2.0	100	200	-	-
>2.0	-	-	-	-

Source: Pushparajah (1977). \* For description of clonal groups see Table 1.

Table 4. Critical ranges of concentration of nutrient elements in frond 17 in mature oil palm (more than six years old).

Nutrient element	Variety		
	Local tall	Dwarf	Hybrid
As % (dry matter)			
N	1.80 - 2.00	1.80 - 2.00	1.80 - 2.20
P	0.12 - 0.14	0.12	0.12 - 0.13
K	0.80 - 1.00	0.60 - 0.80	0.90 - 1.40
Mg	0.20 - 0.30	0.25	0.20 - 0.35
Ca	0.30 - 0.50	0.15 - 0.20	0.32 - 0.35
S	0.13 - 0.17	nd	0.15 - 0.16
Na	0.10 - 0.20	nd	0.15 - 0.17
C1	0.3 - 0.6	nd	0.45 - 0.50
As ppm (dry matter)			
Mn	60 - 115	60	nd
B	9 - 11	8	nd

Source: Uexkull (1992)

Table 5. Critical levels of N,P,K in frond 17 in oil palm

Soil grouping	Range of critical levels (%)		
	N	P	K
Inland soil	2.55 - 2.65	0.17 - 0.18	0.85 - 1.05
Coastal soil	2.85 - 2.95	0.18 - 0.19	1.10 - 1.15

Source: Foster and Goh 1977

## Cocoa

For a long time, fertilizer recommendations for cocoa were based on general schedule, but later, foliar analysis was used. Subsequently in Côte d'Ivoire in Africa in the late 1970s, use of soil diagnosis for assessing fertilizer needs was developed. In South-east Asia, Ling (1990) has developed the combined use of soil and leaf analysis to assess requirements of the major nutrients, N, P and K (Table 7).

## Fruit Trees

Leaf analysis is increasingly being used as a diagnostic tool for fruit tree crops (Raveendranathan 1992). It is generally used as a guide to nutrient

balances. For example in the case of mango, the nutrient ratios  $N/K < 0.5$  and  $K/Ca < 0.2$  are used as critical ratios to guide fertilizer inputs to ensure good-quality fruit. If these nutrient ratios fall below the critical levels indicated, internal tissues break down, adversely affecting fruit quality. Leaf analysis thus makes it possible to adjust nutrient input ratios, so as to ensure fruit quality.

## NEED FOR QUALITY ASSURANCE OF ANALYSIS

Laboratory analysis should ensure precision (reproducibility and repeatability), and accuracy (minimum difference between estimated and true value). The influence of factors such as the operator, equipment, day (and thus temperature),

Table 6. Optimum range of concentration of nutrient elements in frond 14 in mature bearing palms

Nutrient element	Variety		
	Local tall	Dwarf	Hybrid
As % (dry matter)			
N	1.80 - 2.00	1.80 - 2.00	1.80 - 2.20
P	0.12 - 0.14	0.12	0.12 - 0.13
K	0.80 - 1.00	0.60 - 0.80	0.90 - 1.40
Mg	0.20 - 0.30	0.25	0.20 - 0.35
Ca	0.30 - 0.50	0.15 - 0.20	0.32 - 0.35
S	0.13 - 0.17	nd	0.15 - 0.16
Na	0.10 - 0.20	nd	0.15 - 0.17
C1	0.3 - 0.6	nd	0.45 - 0.50
As ppm (dry matter)			
Mn	60 - 115	60	nd
B	9 - 11	8	nd

Sources: Magat (1992) citing Magat (1979) for local tall, Chew (1982) for dwarf and Magat (1988) for hybrid varieties.

Table 7. Range of values of N,P,K in cocoa leaves and soil, and guide to fertilizer rates.

Nutrient element	Nutrient content		Fertilizer rate (kg ha <sup>-1</sup> )
	In leaf (%)	In soil *	
N	i. < 2.0	-	100-150
	ii. 2.0 - 2.6	-	60 - 80
	iii. > 2.6	-	Nil
P	i. < 0.2	< 15 mg kg <sup>-1</sup>	40-70
	ii. > 0.2	a. < 15 mg kg <sup>-1</sup>	15 - 30
		b. > 15 mg kg <sup>-1</sup>	Nil
K	i. < 2.0	< 0.3 c mol kg <sup>-1</sup>	100 - 150
	ii. > 2.0	a. < 0.3 c mol kg <sup>-1</sup>	70 - 80
		b. > 0.3 c mol kg <sup>-1</sup>	Nil

\* P = Bray 2 extr. P; K = exch. K.

Source: Ling 1990

digestion (time and procedure) on the precision of a given method of analysis has been reviewed recently (Pushparajah 1993). The need for standard samples and inter-laboratory cross-checks is important. It must be an integral component of the operations of any laboratory to ensure that its analytical procedures is accurate.

## CONCLUSION

In South-east Asia, where tree-crop agriculture dominates commercial agriculture in rainfed areas, chemical fertilizers have been used for many decades (more than for irrigated rice in some countries). The need for increased efficiency of fertilizer

use was realized early, and this has led to the development of tissue analysis and soil testing as key tools, especially with the major plantation tree crops of rubber, oil palm and cocoa. The efficiency of this approach is continuously being upgraded. However there is a need to implement quality control in laboratories.

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## **DISCUSSION AFTER PAPER PRESENTATION**

Participants discussed the need for a nutrient budget on a national basis. Dr. Koshino pointed out that Japan is importing huge quantities of nitrogen and fertilizer in its imports of food and forage. This is causing a problem of nutrient enrichment in the environment. In the case of Malaysia's rubber exports, this represents an export of carbohydrates rather than nutrient elements such as N and P. Dr. Pushparajah agreed, and said that Thailand is exporting thousands of tons of potassium in cassava to Europe. He emphasized that nutrients going out of each country must be balanced by those coming in.

Several participants were interested in the system of cross checking established for laboratories in Malaysia, and asked for further details. Dr. Pushparajah explained that this had begun in 1971. Originally it dealt only with soil analysis, but later it was expanded to include leaf analysis, and finally fertilizer analysis. There are now about 30 laboratories participating in the program on a voluntary basis, under the supervision of a special committee. These include all government laboratories involved in soil and leaf testing, plus several private ones. Representatives from each laboratory meet every year to discuss problems. At the moment, the two most serious problems are felt to be trace elements, and soil physical parameters such as bulk density. Dr. Hussein added that the laboratories are sent standard soil samples to be analyzed. The committee looks at the performance of individual laboratories, and if there are discrepancies, contacts the laboratory in question to find out what the problem is. Once the laboratory has identified the problem and put matters right, it is required to report to the committee.

Dr. Pushparajah was asked how often fertilizer recommendations developed for a particular crop or site had to be updated. He explained that this depends on the type of crop. In the case of rubber, if the trees are at least ten years old and a specific clone, there is not much need to change the recommendations. In the case of cocoa, if yields are low it is recommended that more fertilizer be applied to build up the level of nutrients. After three or four years, it may be time to change this approach and begin to reduce application levels. He discussed the concept of the maximum yield, and pointed out that with better moisture management and an optimum fertilizer plateau, the recommended nutrient level will have to be moved upwards, as must also be the case if irrigation is introduced.



Dr. Koshino referred to the kinetic method used in Japan to predict N mineralization over time, so as to take into account the important variable of temperature. Dr. Lian suggested that moisture content may also be important in influencing N mineralization rates. For example in paddy fields, management practices such as draining the field and allowing the soil to dry out may have an important effect. Dr. Koshino agreed, and pointed out that a very low soil moisture content affects microbial activity, while a high one leads to leaching losses.

Dr. Zakaria described how shredded palm oil leaves, POME (palm oil mill effluent) and other by-products are used in Malaysia as organic fertilizer in oil palm plantations in Malaysia. He pointed out that the C/N ratio varies in different materials, and that this affects how soon the N is mineralized. For this reason, the C/N ratio is measured in Malaysia, as well as the level of organic N in the soil. Dr. Recel pointed out that in the case of banana plantations, an estimate of the level of N in composted vegetative residues and the level of mineralization in the course of a year makes it possible to use the level of organic matter as a guide to N status. Dr. Lian emphasized the importance of testing N levels on organic fertilizers. Dr. Koshino agreed, and pointed out that the release of N from organic matter may be influenced by drying procedures. If materials are dried under very high temperatures, subsequent N release is slow.

The use of new equipment to improve accuracy and speed of analysis was discussed. Dr. Tasnee recognized the many advantages of these, but emphasized the need to keep the cost of testing down, especially for low-income farmers. Finally, Dr. Lian pointed out that although as soil scientists, they had been devoting much effort to soil and plant testing methods, they should perhaps consider the effectiveness of these methods in improving actual farm practices. In spite of the analysis of numerous soil samples, farmers in Taiwan are still applying excessive amounts of fertilizer. He suggested that soil scientists might go on to study this excessive use of fertilizer and develop programs to reduce it. Dr. Pushparajah pointed out that in the case of Thailand, the range of fertilizers available is limited. Although soil and plant testing might give a sophisticated picture of crop nutrient requirements, farmers are unable to fulfill these if only a single fertilizer grade is available. He suggested that soil scientists should not limit themselves to diagnostic procedures, but should work with policy makers to help ensure that proper fertilizers are readily available, and with farmers and environmentalists to limit fertilizer applications. "We must look beyond our laboratories, and deal with the results of our findings".