THE MANAGEMENT OF SOILS AND FERTILIZERS FOR SUSTAINABLE CROP PRODUCTION IN MALAYSIA

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ABSTRACT

Three main landforms are found in Malaysia — the high mountainous interior under natural forest, the well-drained, undulating uplands planted in rubber (Hevea brasiliensis) and oil palm (Elaeis guineensis); and the lowlands, most of which are planted in wet rice.

Rubber replaced the natural forest on large areas of upland soils (Oxisols and Ultisols) more than 100 years ago. Improved technology for large-scale rubber production generated by the Rubber Research Institute of Malaysia is being utilized far more effectively by the large estates than by smallholders. This technology includes the use of high-yielding clones, balanced fertilizer applications, legume cover crops on steep terrain and proper tapping systems. The Rubber Industry Smallholders Development Agency (RISDA) has used similar technology to improve the production of millions of rubber smallholders. Replacing the natural tropical forest with the man-made monoculture of rubber is being economically and ecologically sustained by sound soil and fertilizer management. Replacing old rubber trees with modern high-yielding clones on highly weathered soils requires careful soil and fertilizer management. In the early 1970s, oil palm began to replace rubber on some better inland soils. Oil palm has a high K and N demand, and if these requirements are met, can produce 25 - 30 mt (fresh-fruit bunches) per hectare per year. The land application of nutrient-rich oil palm factory wastes replaces some of these nutrients, and also minimizes environmental pollution.

INTRODUCTION

Geomorphologically, Peninsular Malaysia consists of a central core of granite mountains running from north to south, with major flood plains running along the coast and in between hilly, well-drained uplands. The mountains and most of the hilly uplands are at present still under natural forest.

The flood plains on the west coast of the peninsula are much more productive (Ng 1977b) than those on the east. The alluvial plains on the west coast are fringed by large mangrove swamps, and are still largely underdeveloped.

The production of plantation tree crops covers vast areas of upland. The widespread use in plantations of superior, high-yielding planting materials since the beginning of this century has led to an increased use of commercial fertilizers (Fig. 1). Since Malaysia's even temperatures permit year-round growth, there is the possibility of a rapid decline in inherent soil fertility through erosion and nutrient loss unless there is careful soil management. The use of ground cover and a nutrient budget are the basic methods in the management of soils and fertilizers for sustained production of plantation tree crops in Malaysia.

This paper examines various methods of soil and fertilizer management currently being used in Malaysia to sustain various crop production systems.

DISTRIBUTION OF SOILS AND AGRICULTURAL SYSTEMS

For operational purposes, the soils of Malaysia can be divided into three broad categories: soils under forest in the mountains of the interior; upland soils under plantation crops, rainfed field crops and forest in the interior uplands; and soils on the alluvial plains. Pedogenetically, soils in the

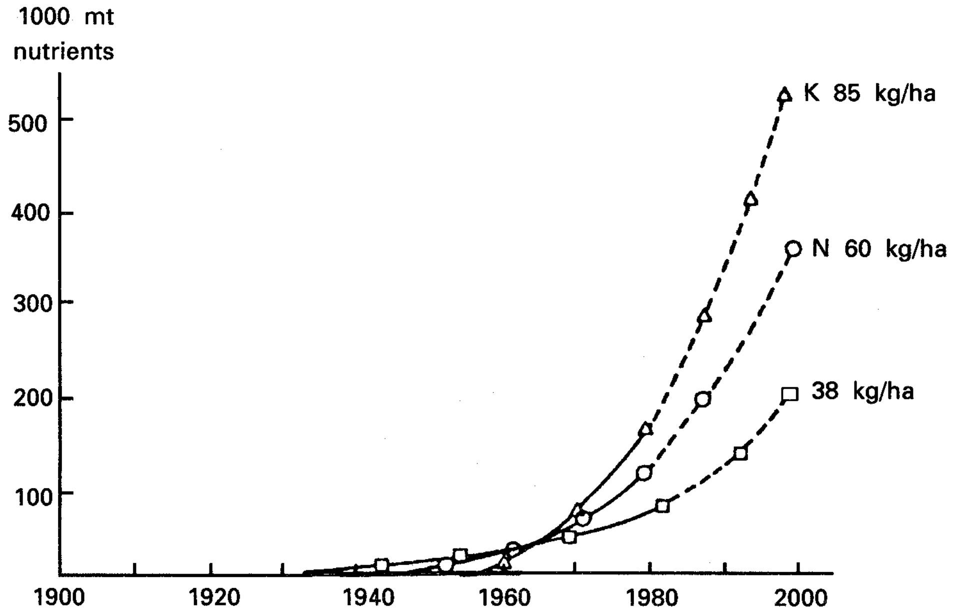

Fig. 1. Trends in fertilizer consumption in Malaysia (1900-2000)

Source: von Uexkull 1983

mountains are young, shallow and are covered by natural forest which is maintained by an efficient nutrient cycle. Inland soils on the undulating upland terrain are deeply weathered, acidic and highly leached, with a low to moderate inherent fertility related to the natural forest cover and the parent rock. They are mainly Oxisols and Ultisols, and occupy some 24 million ha or 72% of the total land area of the country. Although such soils have a good physical make-up, they are devoid of most nutrients, and have a low CEC, a low base saturation and a high aluminum saturation with values often exceeding 80% (Tessens and Shamshuddin 1983).

In contrast, soils on the flood plains are strongly gleyed, contain a relatively high CEC and varying levels of organic matter, and are predominantly silty clay loams or clay loams. The various properties of arable soils and the crops normally grown on them are presented in Table 1.

Rubber

Rubber trees originate from the jungles of the Amazon Basin of South America, and have now replaced the natural forest in much of the interior uplands of Peninsular Malaysia, especially on the west coast. Planting began last century, and by 1940 covered 2 million ha, 60% of which was farmed by smallholders and 40% by large commercial estates. To-day, Malaysia is the world's third largest producer of natural rubber.

The rubber tree has an economic life cycle of 30-40 years. This can be divided into two main phases, the immature period of five years (previously seven years) from planting to tapping, and the mature period during which the trees are tapped. Although the soil management during these two phases is much the same, there are marked differences in their fertilizer management.

Nearly all the early plantations were established on land cleared from virgin forest, and the trees thrived on the high inherent fertility from the organic matter reserves built up over a long period. Overall growth was generally considered satisfactory, even with clean weeding, and fertilizers were not used. However, in experiments with nitrogen (N) and phosphorus (P) fertilizers, better growth was obtained on almost all inland soils but not on alluvial soils (RRIM 1939). Similarly, response to potassium (K) fertilizer depended on the soil type. On coastal and heavier inland soils, added K often depressed growth, especially in the absence of fertilizer N, but on sandier soils, growth was increased. On most soils there was some response to fertilizer,

Table 1. The distribution of economic crops on the inland and coastal soils of Peninsular Malaysia

Terrain	Soil properties limiting crop production	Suitable crop
Upland		
Oxisols, Ultisols	Deep profile, low moisture retention. Al toxicity, acidic	Rubber, oil palm, cocoa, mixed orchard
Coastal		
Marine clays, Inceptisols Entisols	Gleyed, often with poor drainage	Oil palm, coconut, cocoa, rice
Riverine	Water logging, clay	Rice
Sandy	Low moisture content, poor in nutrients	Cashew nut
Peat	Shrinkage, acidic, low nutrient level	Oil palm, pineapple

especially if a combination of N, P and K fertilizers was used, and this became recommended for general use on rubber, once a forest tree, in Malaysia (Bolton 1964).

After World War II, high-yielding clones grown on sandier soils showed magnesium deficiency in the leaves (Bolle-Jones 1954; Bolton and Shorrocks 1961). The fertilizer recommendations of the Rubber Research Institute (1958) were therefore modified to include this element. A mixture of sulphate of ammonia (N), rock phosphate (P), potassium chloride (K), with or without kieserite (for Mg), was recommended for all inland soils, while fertilizer was not considered necessary on alluvial coastal soils.

On the basis of terrain alone, which affects drainage and run-off, two broad groups of soils for rubber were therefore differentiated, and fertilizers are managed accordingly. Under the high rainfall and highly acidic conditions of inland soils, various types of phosphatic rocks are widely used, which slowly release available P to plants over time. Rock phosphates remain a cheap source of P for both rubber trees and leguminous cover crops. They have a high residual value so that they benefit the crop for a long time (Middleton and Pushparajah 1966).

Legume cover crops have long been an important part of soil management for rubber. Initially they were used to provide effective cover against soil erosion in newly planted or replanted rubber on steep terrain, and later to supply additional nitrogen. Over the years, field experiments with various types of cover crops and fertilizers have shown that the amount of fertilizer, especially N, required by young rubber trees can be reduced after the third or fourth year from planting if a good legume cover is maintained (Table 2) (Mainstone 1961, Coulter 1972, and Broughton 1977). However, regular top dressing with rock phosphate during the first few years is required to establish and maintain the legume cover (Watson 1966). With good management of cover crop and fertilizer, trees can be brought into production at only four or five years, reducing the immature, unproductive period by one or two years. Cover crops also protect the soil, and at the same time maintain or even increase its overall fertility.

These management practices represent the basic principles for managing cropping systems in the humid tropics. To maintain soil fertility and sustained crop productivity, soils in Malaysia and other countries of the humid tropics have to be kept moist, covered, cool and undisturbed most of the time. These conditions follow closely those found in the original forest environment which is now occupied by the present rubber plantations.

Oil Palm

Oil palm was first planted in Malaysia in 1917. It now (1990) occupies 2.1 million ha of land, making Malaysia the top world producer of palm oil.

Table 2. General fertilizer shedule for immature rubber trees*

		Nutrients (kg/ha from 1st to 6 yrs)			
		N	P_2O_5	K_2O	MgO
Malaysia	Low K, no legumes	640	250	170	50
	Low K, mixed legumes	225	250	170	50
	Low K, pure legume stand	30	250	170	50
	High K, no legumes	660	260	90	50
	High K, mixed legumes	225	260	90	50
	High K, pure legume stand	30	260	90	50
Indonesia	East Java	290	305	132	50
	West Java & Sumatra	251	274	217	50
Thailand	Low K soils	250	270	220	50
	High K soils	290	300	130	50

Source: Pushparajah 1984
* 450 trees/ha; period of 66-72 months

As a result of the crop diversification policy begun in 1969, this crop replaced rubber on better inland and coastal soils, especially from 1956 to 1975 when the price of rubber fell. The oil palm, unlike rubber, is managed largely on an estate basis, and only a small percentage is grown by smallholders.

Like rubber, oil palm has two growth phases: the immature and the production phase. The nutrient requirements were determined by weighing the dry matter production, yield and nutrient uptake of palms from one up to ten years after planting. These studies showed that the oil palm is a more demanding crop than rubber, in terms of nutrient requirements, both for early growth and for mature production (Ng and Thamboo 1967, Ng *et al.* 1968), as is shown in Table 3.

From these data, it is obvious that oil palms need a soil with a high inherent fertility level. While N can be partially supplemented through the use of legume cover crops, particularly on upland soils previously under rubber (Broughton 1977, Agamuthu *et al.* 1981), the high demand for K has to be met by fertilizers, except on soil with high K reserves. Oil palms on soils with high K reserves give higher yields and do not respond to K fertilizer, unlike those on soils with low K reserves (Hew *et al.* 1973, Tan 1973). From the point of view of the nutrient budget for the crop at various growth stages (Fig. 2), oil palm shows a sharp rise in its uptake of major nutrients, particularly K and N, from the second year after planting. This uptake levels off after 5-6 years of growth. It is thus of critical importance to provide adequate nutrition through appropriate management of fertilizer and cover crops while the palms are immature, if early harvests are to be large and rapid increases in yields to be sustained. These would bring in an early return from investment.

If nutrient budget data is compared to the ability of soils to supply these nutrients, fertilizer requirements can be determined to give economic production levels (Hew and Ng 1968, Ng 1977a). Soils with a low K content, mainly upland Ultisols and Oxisols, require earlier and heavier applications of potash than those with high K reserves. Magnesium is also important, particularly on the highly weathered and leached soils found in some inland areas (Tan 1979). Nitrogen N is the most expensive nutrient per unit applied. Palms on heavy inland soils formerly planted in rubber require good, early legume cover if maximum early growth of the crop is to be sustained. The value of legume crops to oil palm production, both as ground cover and as a source of N, has been clearly demonstrated (Hew *et al.* 1973). The symbiotic N fixation of legume cover crops can be exploited even more effectively if low-cost pre-emergence herbicides are used (Agamuthu *et al.* 1980, 1981). The banking of nutrients obtained from the soil and from applied fertilizers by all vegetative cover—legume crops and natural ground cover—can be utilized as grazing by sheep or cattle. This further benefits the nutrient budget and nutrient cycling on oil palm plantations.

Proper nutrient management is needed to balance the inputs and losses of the different nutri-

Table 3. Estimated annual nutrient uptake by 6-8 year old oil palms

Plant (palm) part	N	P	K (kg/ha^{-1})	Mg
Fresh fruit bunches (25 mt)	73.3	11.6	93.4	20.8
Vegetative organic matter	108.1	12.0	141.9	33.9
Male flowers	11.2	2.4	16.2	6.6
Total	192.6	26.0	251.5	61.3

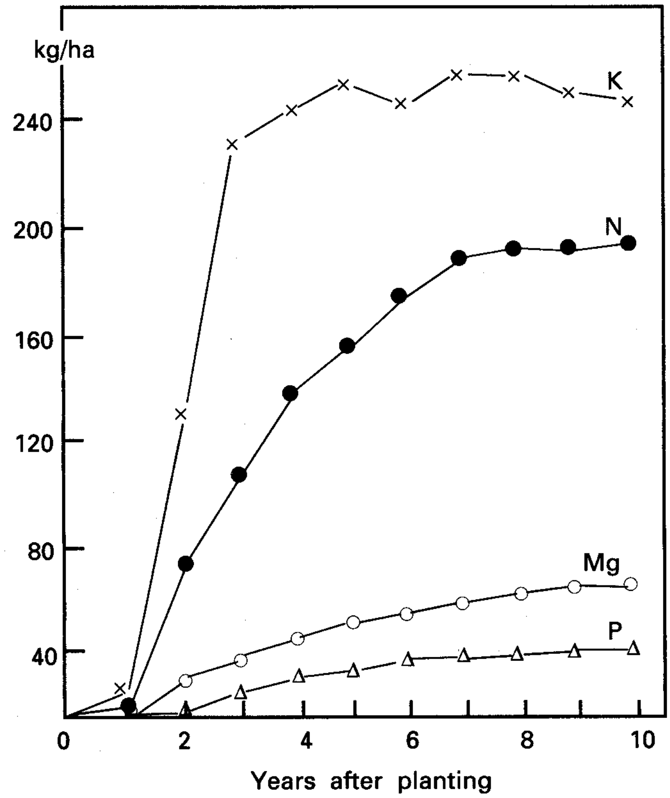

Fig. 2. Nutrient up-take of oil palms for the first 10 years after planting

Source: Ng (1977a)

ents. This is particularly important with the N:K and K:Mg ratio, and also with micro-nutrients on certain soils such as peat. On soils with a low K content, a good K-N fertilizer balance can give improved yields even from mature palms on sandy soils (Ollagnier and Ochs 1973). An increased supply of N and K without an adequate supply of Mg on soils with a low Mg status can lead to the development of Orange Frond symptoms in younger palms — a nutritional disorder which later depresses growth and eventually yields.

Using the improved planting materials produced by tissue culture and good management practices, average yields have increased from 25 to 30 mt/ha. At the same time, replanting oil palm in old plantations has highlighted the critical role of micronutrients. Immature trees can be badly damaged by boron (B) and copper (Cu) deficiency (Rajaratnam

1973a). Boron deficiency is widespread because the available boron in the surface soil has been exhausted by the previous oil palm crop, while applications of potash also suppress B uptake by the palm (Rajaratnam 1973b). As a preventive measure, fertilizer management for replanted estates includes the application of about 100-150 g borate fertilizer two or three times a year from the second year after replanting (Ng 1977a).

Nutritional disorders of palms on deep peat (>2m) are reflected in the common incidence of palms with chlorotic and dessicated leaves, a condition which Turner and Bull (1967) termed 'Peat Yellow'. Such palms produce no fruit bunches. This situation was assessed by Ng *et al*. (1974) who concluded that Cu deficiency was responsible for the disorder, and could be prevented by repeated foliar applications of $CuSO_4$ to immature palms. Singh (1983) also showed that foliar spraying with $ZnSO_4$ reduced peat yellow symptoms.

Elsewhere on normal soils, sustained high yields produce large amounts of factory wastes, the disposal of which can be a problem to the industry and the environment. The land application of nutrient-rich wastes from palm oil factories has been tested on a large scale (Wood 1977; Wood *et al.* 1979), and found to be an efficient means of nutrient recycling. A better understanding of the actual nutrient uptake-path, sources etc. by high-producing palms has also been achieved by tracer studies (Zaharah *et al.* 1991). These may ultimately produce systems of fertilizer management which are economically and environmentally acceptable for large-scale plantations in the humid tropics.

Cocoa and Coconut

When cocoa is grown under mature coconut, this dual crop combination has special nutrient requirements. Both crops have an extensive surface root system (Tan 1979, Ng 1968). When cocoa is planted in the shade provided by mature coconut, balanced nutrient management is essential to satisfy its high nutrient requirements during early growth and yield. The nutrient uptake by cocoa is high (though not as high as that of the oil palm), and on less fertile inland soils, fertilizers are needed in large quantities. Some of these requirements have been met through the appropriate use of nutrient-rich oil palm residues, coconut husks and other agricultural wastes (Sharifuddin and Zaharah 1987). Mycorrhizal root associations, such as vesicular-arbuscular mycorrhizal inoculation or VAM, (Chulan 1991, Chulan and Ragu 1988) have also been successfully exploited to give efficient use of limited amounts of P in highly weathered soils.

Pepper

Pepper is grown mainly by smallholders in Sarawak. As with other perennial crops, the nutrient demand is high during early growth and early maturity. At a planting density of 1600 vines/ha, the total nutrient uptake could be around 200 kg N, 13 kg P, 156 kg K, 18 kg Ca and 68 kg Mg per hectare per year from the third to the eighth years after planting (Wong 1986).

Covering the soil and terracing conserve soil moisture and fertility, and reduce soil losses by as much as 150% (Hatch 1982). Sarawak pepper is being sold for a good price on the international market, and further research and development work is now in progress.

Orchard Fruit

The traditional *dusun* or mixed horticultural holding of the Malaysian smallholder needs little soil and fertilizer management, apart from annual clearing of the soil around durian trees. However, the development of commercial production for export, using improved planting materials planted at a high density, means a higher nutrient demand from high-yielding fruit crops. At present, fertilizers are applied regularly around each tree, and the high K demand of fruit crops such as banana, papaya and carambola is partly met by using K-rich oil palm residues.

Rice

The sustainable production of annual crops such as rice will require major changes in current production methods. At present, the inherent soil fertility of rice-growing areas on the west coast of the peninsula and flat alluvial areas in Sarawak and Sabah is almost exhausted, as a result of being continuously cropped with high-yielding varieties. Rain-fed rice production is much less reliable than irrigated rice. Since 1979, smallholders have received enough fully subsidized fertilizer for up to six acres at the recommended rate of 60 - 90 kg/ha N (Urea), 30 - 40 kg/ha P (soluble P source), and 20 - 30 kg/ha K (muriate of potash). Even with relatively high yields of 4 - 5 mt/ha^{-1}, the amount of nutrients directly removed in the grain is small, especially if crop residues are returned to the soil. Field studies indicate that 34 - 98 kg N/ha are removed by the rice crop, of which 34 - 56 kg N/ha are the original soil N.

Other nutrients such as P,K, Ca, Mg and even S, need to be formulated in a balanced manner. For sustainable production, greater attention should be given to the management of the supply of plant nutrients from renewable sources (Patnaik and Rao 1979). The use of direct seeding may make possible the more efficient use of fertilizer as well as natural N sources.

Other Food Crops

In Malaysia, annual food crops such as maize and groundnut generally fail on soils suited to tree crops. Excessive erosion, high acidity and aluminum saturation are among the factors which severely limit the yields of annual food crops grown on upland soils (Mokhtaruddin *et al.* 1984, Sharifuddin *et al.* 1984). Data on the tolerance level of various food crops to aluminium saturation (Fig. 3) makes it possible to select appropriate food crops for various highly weathered upland soils.

With the appropriate use of locally produced ground lime and an appropriate legume-cereal crop rotation, Anuar (1991) showed that it was possible to obtain sustained yields of about 2 mt/ha^{-1} from groundnut and about 6 mt/ha^{-1} from corn grown on an Ultisol in Malaysia. With such a cropping system, the limed Ultisol can also produce between 50 - 100 kg/ha^{-1} of plant N from inoculated groundnut, to supplement the N needs of the succeeding corn crop.

MEETING CROP NUTRIENT REQUIREMENTS

Improved genetic planting materials of tree crops such as rubber, oil palm, cocoa, coconut and fruit require substantial amounts of applied nutrients if they are to give their maximum economic potential yield. The destructive nature of the humid tropical climate in reducing overall soil fertility following forest clearance is overcome by replacing that forest with a tree crop ecosystem. Both are stable and sustainable systems, but the latter gives a better economic return and is more demanding in terms of nutrient supply. On appropriate terrain, both protect the soil against dehydration, destruction of the soil structure and erosion, and add organic matter to the surface soil. The nutrient cycle which maintains the sustainability of the forest ecosystem before clearance is temporarily broken during the early phase of tree crop establishment. Providing immediate soil cover by means of an appropriate fast-growing legume cover crop protects the soil and helps to build up a pool of nutrients in the topsoil, at the same time restoring soil fertility temporarily lost after forest clearance. Cover crops of this kind take advantage of one of the assets of the tropical climate – that the warm, moist conditions favor the rapid re-establishment of vegetation. This generally takes longer in a temperate environment with its shorter growing season.

The use of perennial crops tolerant of acid soils and aluminum toxicity, together with applications of rock phosphate to both the legume cover and the main tree crops, is another technique being widely used to overcome the chemical constraints, particularly the lack of P, found in highly weathered soils in upland regions. Low-cost rock phosphate is widely used, taking advantage of the soil's acidic nature which results in the slow release of P to tree and cover crops.

Rapid early growth of tree crops has thus been achieved with balanced fertilizer management (von Uexkull 1990). This gives the maximum growth required for high and early yields of tree crops representing improved superior genetic materials. This in turn gives early return on investment, particularly for oil palm (Ng 1977a). Under such management, continuous sustained high production is being achieved. This has led to the production of massive quantities of agroindustrial wastes which at times have caused environmental problems. The application of nutrient-rich oil palm mill wastes to mature crops is one economic utilization of such by-products. Wood (1977, Wood *et al.* 1979) has suggested that oil palm effluent should be treated before it is applied, to make more organic N available to plants. The recycling of agro-wastes reduces the need for chemical fertilizer in mature oil palm and cocoa plantations (Watson 1966, Broughton 1977), restoring some of the potassium and nitrogen removed with the harvested crop (Table 4). Full exploitation of the yield potential of improved strains of rubber, oil palm, cocoa and fruit by improving soil fertility has been an outstanding feature of Malaysian agricultural development for more than six decades.

The fertility of soils under major plantation crops, mainly Oxisols and Ultisols, is being sustained, and in some cases has been appreciably improved beyond that found under the original rainforest. The continuous supply of organic matter (pruned fronds) and applied agroindustrial wastes, together with zero tillage in mature plantations, helps to maintain continuous and sustained high productivity of aluminum-tolerant tree crops on the highly weathered and leached acidic soils of Malay-

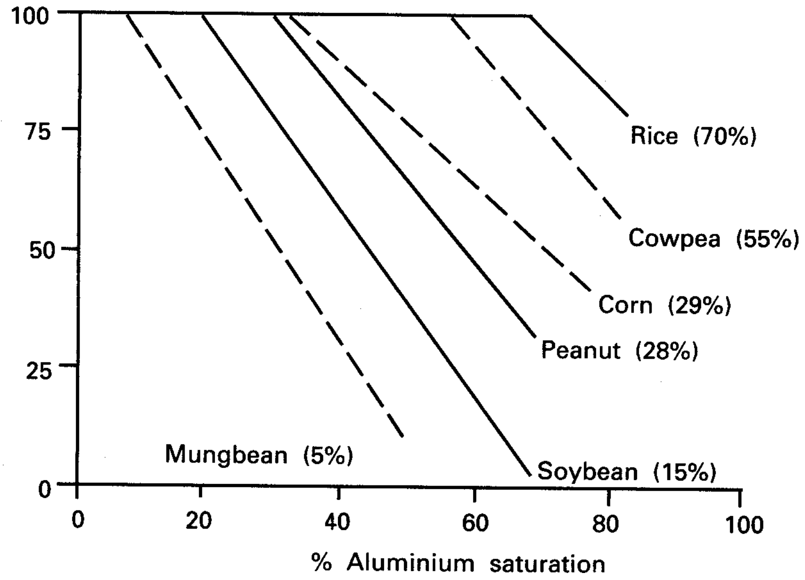

Fig. 3. Tolerance of selected food crops to % aluminium saturation in an Ultisol

Source: Wade *et al.* 1988
Values in parentheses are the critical levels

Table 4. Nutrients removed in major tropical crops

Crop	Yield (mt/ha)	Nutrient removal N	P	K Kg/ha^{-1}	Ca	Mg	Reference
Rubber	1.1	7	1.3	5	1.1	0.1	Bolton (1964)
Oil palm	25.0	73	12	94	-	21	Ng (1977a)
Cocoa	1.0	31	5	54	5	5.2	Thong and Ng (1978)
Rice	4.5	87	-	-	-	-	De Datta (1986)
Banana	6.0	13	2	79	6	3	Joseph (1971)
Durian	5.5	14	2	24	2	3	Yaacob (1983)
Papaya	1.0	133	20	162	33	19	Awada and Suehisa (1971)

sia. The production of animal feeds based on palm oil by-products, still at an early stage, will further improve nutrient cycling, and further demonstrate how sound soil and fertilizer management can sustain crop productivity without destroying the tropical ecosystem in the process.

REFERENCES

Anuar, A.R. 1991. Nitrogen Contribution by Groundnut in a Rotation Cropping System on an Ultisol. Unpub. Ph.D Thesis, Univ. Pertanian Malaysia, Serdang, Malaysia.

Agamuthu, P., Y.K. Chan, R. Jesinger, K.M.

Khoo, and W.J. Broughton. 1980. Effect of diphenyl ester pre-emergence herbicides on legume cover establishment under oil palm. *Agro Ecosystems* 6: 193-208.

Agamuthu, P., Y.K. Chan, R. Jesinger, K.M. Khoo, and W.J. Broughton. 1981. Effects of differently managed legumes on the early development of oil palm. *Agro Ecosystems* 6: 315-323.

Awada, M. and R. Suehisa. 1971. Nutrient removal by papaya fruits. *Hort Sci.* 5: 182.

Bolle-Jones, E.W. 1956. Nutrition of *Hevea brasiliensis. II.* The interrelationships between magnesium, potassium and phosphorous. *Jour. Rubber Research Inst. Malaya* 14: 231.

Bolton, J. 1964. The manuring and cultivation of *Hevea brasiliensis. J. Sci. Fd. Agric.* 15: 1-8.

Bolton, J. and V.M. Shorrocks. 1961. Effects of various covers on the performance of *Elaeis guineensis* Jacq. on different soils. In: *Proceedings of the Malaysian International Oil Palm Conference.* Kuala Lumpur, Malaysia 1976, pp. 501-525.

Broughton, W.J. 1977. Effects of various covers on soil fertility under *Hevea brasiliensis* Muell and on growth of the tree. *Agro Ecosystem* 3: 147-170.

Chulan, A.H. 1991. Effect of fertilizer and endomycorrhizal inoculum on growth and nutrient uptake of cocoa (*Theobroma cacao L.*) seedlings. *Biol. Fertil. Soils* 11: 250-254.

Chulan, A.H. and P. Ragu. 1986. Growth response of *Theobroma cacao* L. seedlings to vesicular-arbuscular mycorrhizal inoculation. *Plant Soil* 96: 279-285.

Coulter, J.K. 1972. Soils of Malaysia. *Soil Fert.* 35: 475-498.

De Datta, S.K. 1986. Improving fertilizer nitrogen efficiency in lowland rice in tropical Asia. *Fertilizer Research* 9: 171-186.

Hatch, T. 1982. *Terrace Building in Sarawak.* Tech. Paper No. 7., Dept. Agric., Sarawak.

Hew, C.K. and S.K. Ng. 1968. A general schedule for manuring oil palms in West Malaysia. *Planter* 44: 417-429.

Hew, C.K., S.K. Ng and K.P. Lim. 1973. The rationale of manuring oil palms and its economics in Malaysia. In: *Advances in Oil Palm Cultivation,* R.L. Wastie and D.A. Earp (eds.). Kuala Lumpur: Incorporation Society of Planters, pp. 306-322.

Joseph, K.T. 1971. Nutrient content and nutrient removal in bananas as an initial guide for assessing fertilizer needs. *Planter* 47: 7-10.

Mainstone, B.J. 1961. Effects of ground cover types and continuity of nitrogenous fertilizer treatment upon the growth to tapping maturity of *Hevea brasiliensis. Proc. Nat. Rubber Research Conf.* 1960, Kuala Lumpur, Malaysia. P.362.

Middleton, K. R. and E. Pushparajah. 1966. The use of phosphates in the cultivation of *Hevea brasiliensis. Outlook Agric.* 5: 69-73.

Mokhtaruddin, A.M., T. Jamal, W.H. Wan Sulaiman and A.R. Anuar. 1984. Yield reduction due to loss in soil fertility through erosion. In: *Proc. 5th. Asean Soil Conf.* Bangkok, Thailand. P. E6.1-E6.7.

Ng, S.K. 1968. Padi soils of West Malaysia. In: *Proceedings of the Third Malaysian Soil Science Conference.* Kuching, Sarawak, pp 67-71.

Ng, S.K. 1977a. Review of oil palm nutrient and manuring: Scope for greater economy in fertilizer usage. *Oleagineux* 32: 197-209.

Ng, S.K. 1977b. Intensifying cultivation of coastal alluvial soils for agricultural production in Peninsular Malaysia. *Proceedings, International Seminar on Soil Environment and Fertility Management in Intensive Agriculture.* Tokyo, pp. 575-581.

Ng, S.K., Y.P. Tan, E. Chan and S.P. Cheong. 1974. Nutritional complexes of oil palms planted on peat soil in Malaysia. II. Preliminary results of copper sulphate treatments. *Oleagineux* 29: 445-456.

Ng, S.K. and S. Thamboo. 1967. Nutrient contents of oil palms in Malaysia. I. Nutrients in reproductive tissue fruit bunches and male inflorescence. *Malay. Agric. Jour.* 46: 3-15.

Ng, S.K., S. Thamboo and P. de Souza. 1968. Nutrient contents of oil palms in Malaysia. II. Nutrients in reproductive tissue, fruit bunches and male inflorescence *Malay. Agric. Jour.* 46: 332-391.

Ollagnier, M and R. Ochs. 1973. Interaction between nitrogen and potassium in the nutrition of tropical oil plants. *Oleagineux* 28: 493-508.

Patnaik, S and M.V. Rao. 1979. Sources of nitrogen for rice production. In*: Rice and Soils*. International Rice Research Institute, College, Laguna, Philippines, pp. 25-44.

Pushparajah, E. 1984. Nutritional status and fertilizer requirements of Malaysian soils for *Hevea brasiliensis*. Unpub. D. Sc. Thesis, University of Ghent, Belgium.

Rajaratnam, J.A. 1973a. The effect of boron deficiency on the yield of oil palms in Malaysia. In: *Advances in Oil Palm Cultivation*, R.L. Wastie and D.A. Earp (eds.). Kuala Lumpur: Incorporated Society of Planters, pp. 306-322.

Rajaratnam, J.A. 1973b. Application, absorption and translocation of boron in oil palm. II. Age of palm, frequency of application and influence of N and K. *Experimental Agric.* 8: 141-145.

RRIM. 1939. *Annual Report.* Rubber Research Institute of Malaya, p. 63.

RRIM. 1958. R.R.I. *Plant Bulletin* 35: 46.

Singh, G. 1983. Micronutrient studies of oil palm on peat. Paper presented at the seminar on Fertilizers in Malaysian Agriculture, Malaysia Soc., Serdang, Malaysia.

Sharifuddin, H.A.H., M.N. Mohd. Yusof, J. Shamshuddin and M. Norhayati. 1984. Management of soil acidity in Malaysia. In: *Management of Acid Soils in the Humid Tropics of Asia*, E.T. Craswell, and E. Pushparajah (eds.). ACIAR-IBSRAM, Bangkok, pp. 72-79.

Sharifuddin, H.A.H. and A.R. Zaharah. 1987. Utilization of natural and agricultural waste products in Malaysian agriculture. Paper presented at the Organic Farming Conference, Khon Kaen, Thailand.

Tan, K.S. 1973. Fertilizer trials of oil palms on inland soils on Dunlop estates. In: *Advances in Oil Palm Cultivation*, R.L. Wastie and D.A. Earp (eds.). Kuala Lumpur: Incorporated Society of Planters, pp. 248-279.

Tan, K.S. 1979. Root development of oil palm on inland soils of West Malaysia. In: *Soil Physical Properties and Crop Production*, R. Lal and D.J. Greenland (eds.). John Wiley & Co., N. York, pp. 363-374.

Thong, K.C. and W.L. Ng. 1978. *Growth and Nutrient Composition of Monocrop Cocoa Plants on Inland Malaysian Soils.* Preprint, International Conference on Cocoa and Coconut, Malaysia.

Tessens, E. and J. Shamshuddin. 1983. *Quantative Relationship between Mineralogy and Properties of Tropical Soils.* University Pertanian Malaysia, Serdang, Malaysia. 190 pp.

Turner, P.D. and R.A.Bull. 1967. *Diseases and Disorders of Oil Palm in Malaysia.* Incorp. Society of Planters, Malaysia.

von Uexkull, H.R. 1983. Potash and magnesium efficiency research in the tropics. Paper presented at the IFDC-FERRIT Course, University Pertanian Malaysia, Serdang, May, 1983.

von Uexkull, H.R. 1990. Balanced fertilizer use of sustained productivity of some major tropical tree crops. In: *Proceedings of the International Symposium on Balanced Fertilization*, China, pp. 223-231.

Wade, M.K., D.W. Gill, H. Subagjo, M. Sudjadi and P.A. Sanchez. 1988. *Overcoming soil fertility constraints in a transmigration area of Indonesia*. Tropsoils Bulletin 88-01. North Carolina State University, USA. 60 pp.

Watson, G.A. 1966. Cover plants in Malayan rubber plantations. *Wld. Crop* 15: 48-52.

Wong, T.H. 1986. Agronomic recommendations for pepper cultivation in Sarawak. In: *Pepper in Malaysia*, C.F.J. Bong, and M.S. Said (eds.). University Pertanian Malaysia, Sarawak Campus, Sarawak, pp. 77-87.

Wood, B.J. 1977. A review of current methods of dealing with palm mill effluent. *Planter* 17: 477-495.

Wood, B.J., K.R. Pillai and J.A. Rajaratnam. 1979. Palm oil mill effluent disposal on land. *Agric. Wastes* 1: 103-127.

Yaacob, O. 1983. The growth and nutrient uptake in durian on an Oxisol at Serdang, Malaysia. *Comm. in Soil Sci. and Plant Anal.* 14,8: 689-698.

Zaharah, A.R., H.A.H. Sharifuddin and M. Ahmad Sahali. 1991. Assessing the availability of three phosphate fertilizer sources to corn using ^{32}p isotope dilution technique. Paper presented at the Soil Science Conference of Malaysia, Genting Highlands, 4-5 March, 1991.