Mineral Nutrition, Growth and Nutrient Cycle of Hevea brasiliensis II. Nutrient Cycle and Fertiliser Requirements

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The quantities of nutrients involved in the nutrient cycle of rubber plantings have been assessed and comparisons drawn between the nutrient requirements of the tree and the amounts of nutrients commonly applied as fertilisers. The amounts of sulphur and phosphorus applied in fertilisers exceed tree requirement whereas those of potassium, magnesium and to a lesser extent calcium fall considerably short: fertiliser nitrogen together with nitrogen fixed symbiotically and nitrogen in rainfall is about equal to the nitrogen requirement of one planting.

The requirement for fertilisers throughout the life of a planting is discussed with reference to soil nutrient content, and recommendations for manuring, particularly of mature rubber, are proposed.

Data on the total nutrient content of trees up to thirty-three years old have already been presented (SHORROCKS, 1965a): the particular trees sampled in this study were regarded as typical of the various ages considered, and the nutrient content data are here used as estimates of the nutrient requirements for growth through the life of one planting of *Hevea*.

It is now possible, by considering tree nutrient requirement data together with the soil nutrient content and cultivation practices that affect soil nutrients, not only to have a better understanding of some aspects of the nutrient cycle of *Hevea*, but also to assess the long term effects of cultural practices on the soil nutrient reserves.

In this paper only those nutrients commonly supplied as fertilisers, namely nitrogen, phosphorus, potassium, magnesium, calcium and sulphur, are considered. Discussion of the nutrient cycle will be restricted to that in operation once the rubber is planted and only a brief consideration will be given to the changes in nutrient content of the soil-vegetation system that occur when the jungle or rubber is felled: this latter topic has been considered by WATSON (1964) and WATSON *et al.* 1964c). The need for discrimination in fertiliser utilisation, particularly with mature rubber, according to soil conditions and fertiliser history is of particular importance (RUBBER RESEARCH INSTITUTE OF MALAYA, 1964a): accordingly the phases of the nutrient cycle will be considered largely from the point of view of providing a basis for the discriminatory use of fertilisers.

THE NUTRIENT CYCLE

The phases and processes involved in the nutrient cycle of a rubber planting are discussed below. Quantitative data are not availabe for all aspects of the cycle, nor for a wide variety of soil and site conditions, but sufficient data are available to indicate the general level of nutrients contained in the tree, in the ground vegetation, and also in a range of Malayan soils, so that an approximation of the total amounts of nutrients involved in the cycle can be made.

Transfer of Nutrients Between Soil and Vegetation

Uptake of nutrients. Nutrients are being continuously transferred between the soil,

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the tree and the ground vegetation. The uptake and accumulation by the tree is the major process in this cycle, although in the early years after planting uptake of nutrients by vigorous leguminous cover plants, growing in the almost open conditions, can exceed that by the tree. WATSON (1964) reports contents of 284 kg N, 25 kg P, 110 kg K, 34 kg Mg and 114 kg Ca per hectare in creeping legumes at two years after planting; as the covers die back under the developing tree shade, these nutrients are returned to the soil and are thus again in active cycle early in the life of a planting.

In mature plantations any persisting ground covers are likely to play a minor role since, except under particular circumstances, they do not develop vigorous growth under shade.

After the first two to three years, the trees assume a dominant position in the nutrient cycle. Nutrients are taken up in considerable quantities and a large proportion are immobilised within the roots, trunk and main branches, whilst smaller proportions remain in active cycle by returning to the soil surface in the annual defoliation at wintering, by seed and branch fall, and by rainwash of leaves. Small quantities of the nutrients will also be released to soil by sporadic root death, particularly of surface feeding roots during periods of dry soil conditions.

Annual leaf, branch and fruit fall. The weight of annual lamina and petiole fall in a mature plantation is likely to vary between 3,700 kg and 7,700 kg per hectare, these being the amounts of leaf found on the tree at any one time (SHORROCKS, 1965a); however, owing to leaf formation and defoliation occurring during the year this estimate is probably low. The estimated nutrient content of this leaf fall is considerable and in terms of fertiliser equivalent the quantities of nitrogen and potassium are about double those applied annually in the normal fertiliser schedule (*Table 1*). No estimate is available for the return of nutrients by branch fall but it is evident from the limited data on amount of branch fall (SHORROCKS, 1965a) that further appreciable quantities will be involved. On the basis of an annual fruit fall of 160 kg per ha, (SHORROCKS, 1965a), consisting of 44 kg of seed and 116 kg of capsules, the amounts of nutrients returned annually per hectare to the soil have been calculated following analysis of seed and capsules of clone RRIM 501: only small amounts, about 1.7 kg N, 1.8 kg K, 0.2 kg Mg, 0.3 kg Ca and 0.2 kg P, are involved.

Rainwash of leaves. Rainfall may leach considerable quantities of nutrients from tree canopies and in a study carried out over a

TABLE 1. ESTIMATED ANNUAL NUTRIENT RETURN IN LEAF FALL AND ANNUAL FERTILISER APPLICATION

(Annual fertiliser application based on application of 250 kg per ha R.R.I.M. Mixture Magnesium C_2, approximately 2 cwt per acre)

Element	Leaf fall			Annual fertiliser application kg per ha
	kg per ha	Equivalent fertiliser, kg per ha		
Nitrogen	45—90	214—428	ammonium sulphate	155
Phosphorus	3—7	19—44	Christmas Island rock phosphate	60
Potassium	10—20	20—40	potassium chloride	15
Magnesium	9—18	57—114	kieserite	20
Calcium	60—120	200—400	Christmas Island rock phosphate	60

Nutrient content of both laminae and petioles have been included on the basis that the weight of petioles accounts for 15% of leaf fall (SHORROCKS, 1965a) and on the following nutrient concentrations (all %) in freshly fallen leaves:

	N	*P*	*K*	*Mg*	*Ca*
Laminae	1.28	0.10	0.24	0.25	1.61
Petioles	0.78	0.06	0.55	0.17	1.80

six months' period it was found that with 100 inches of rain per annum about 10 kg nitrogen, 20 kg potassium, 0.5 kg phosphorus, 1.5 kg magnesium and 15 kg calcium may be leached out of the foliage annually.

Nutrient additions to the cycle. Nutrients are added to the cycle by fertiliser applications (which are considered later), and by rainfall; nitrogen may also be introduced into the cycle by symbiotic nitrogen fixation in the root nodules of leguminous cover plants (see below) and by non-symbiotic nitrogen fixation by free-living soil bacteria. There is considerable disagreement regarding the amounts of nitrogen fixed non-symbiotically, some workers estimating that as much as 40 kg per hectare per annum of nitrogen may be fixed, but it appears that 6 kg per hectare per annum of nitrogen would be a more reasonable estimate (ALLISON, 1955).

Limited analytical data on rain water in Malaya collected in the open, indicates that with an annual rainfall of 100 inches approximately 20 kg nitrogen, 12 kg potassium, 3 kg magnesium, 38 kg calcium and 0.2 kg phosphorus may be added to 1 hectare of soil per annum. The amount of nitrogen is similar to that reported by NYE AND GREENLAND (1960) in Ghana, when due allowances are made for the amount of rainfall, but the levels of phosphorus, potassium and magnesium are lower, and calcium higher, than the values reported by these workers. It is possible that the relatively high value for calcium deposited in the rain is due to the location of a cement factory approximately ten miles away from the point of rainfall collection.

Nutrient losses from the cycle. Nutrients may be lost from the cycle by leaching through the soil, by surface erosion, by denitrification and volatilisation of nitrogen, by their removal in latex from the trees and by removal of vegetation during clearing and replanting operations. Quantitative data are given below for the latter two processes.

Replanting. The nutrient content of the soil-vegetation system will be depleted during the clearing of the land from jungle and in preparation for replanting of old rubber. Exposure of the soil followed by erosion and by increased mineralisation of the organic matter and the subsequent losses of nitrate-nitrogen and cations by leaching, can rapidly result in a marked deterioration of the soil unless a ground vegetation cover is quickly established (WATSON *et al.*, 1964c).

During replanting operations the manner of disposal of the old rubber trees can also markedly affect the nutrient content of the soil-vegetation system. The trees after felling or poisoning are usually either stacked into heaps and burnt or left to decompose, or the timber is removed for use as firewood. The amounts of nutrients contained in the timber (here taken to be the trunk and brown branches) are considerable, as can be seen from *Table 2.*

TABLE 2. ESTIMATED NUTRIENT CONTENT OF TRUNK AND BRANCHES AT REPLANTING

(Data from SHORROCKS (1965a), relating to 33-year-old-trees)

Element	kg per ha	Equivalent fertiliser, kg per ha	
Nitrogen	1389	6614	ammonium sulphate
Phosphorus	218	1380	C.R. rock phosphate
Potassium	989	1986	potassium chloride
Magnesium	328	2083	kieserite

1 kg per hectare = 0.89 lb per acre

It can be appreciated that complete removal of the timber from the land results in a marked depletion of the soil-vegetation system; even after only one planting such depletion is likely to be serious on soils of low total nutrient content. If the timber is stacked and burnt most of the nitrogen and sulphur will be lost to the atmosphere, and other nutrients will be concentrated at the burnt sites giving an enriched soil at a few localities and an impoverished soil over the rest of the field.

It is evident that it would be preferable to let the timber decompose on the ground in the inter-row areas, returning the nutrients slowly to the soil, rather than to waste large quantities of nitrogen by burning, or removing, all nutrients with the timber from the land.

Soil nutrient content. Malayan soils are typically highly leached and have a low nutrient content, but considerable variation may occur depending upon their derivation and history. Data have been grouped in *Table 3* to show the range of concentrations of nitrogen, phosphorus, potassium and magnesium found in the more common Malayan soils, and in *Table 4* the nutrient content in kg per hectare of the top 18 in. of soil is

TABLE 3. RANGE IN NUTRIENT COMPOSITION OF SOME MALAYAN SOILS (0—12 IN. DEPTH)
(Data obtained from the unpublished work of Owen and Guha)

Soil series	Total N%	Acid—extractable P, p.p.m.	Acid—extractable K, p.p.m.	Acid—extractable Mg, p.p.m.
Selangor	0.10—0.30	120—400	800—2200	
Holyrood/Chemor	0.05—0.12	80—250	40—300	15—400
Rengam and	0.05—0.12	80—250	40—160	15—100
Ulu Tiram			200—1000	60—280
Kuantan	0.15—0.20	250—1300	40—200	120—800
		1300—2900		
Serdang/Munchong	0.04—0.11	40—180	200—2000	25—250
Batu Anam	0.05—0.17	40—150	800—1400	
Malacca	0.10—0.20	60—250	150—2500	60—280
Seremban	0.05—0.12	130—250	700—1800	120—480

Potassium and magnesium extracted in 1:1 hydrochloric acid
Phosphorus extracted in sulphuric/perchloric acid mixture

TABLE 4. RANGE IN TOTAL NUTRIENT CONTENT OF THE TOP 18 INCHES OF SOME MALAYAN SOILS (KG PER HA) AND THE MINIMAL REQUIREMENT FROM SOIL NUTRIENT RESERVES DURING THE LIFE OF ONE PLANTING
(*Calculated as the difference between the amounts of applied fertiliser nutrients and the* nutrient requirement of the tree)

Soil series	N	P	K	Mg
Selangor	6,750—20,000	800—2,700	5,400—14,800	
Holyrood/Chemor	3,400—8,100	540—1,700	270—2,000	100—2,700
Rengam and	3,400—8,100	540—1,700	270—1,100	100—670
Ulu Tiram			1,350—6,700	400—1,900
Kuantan	10,100—13,500	1,700—8,800	270—1,350	800—5,400
		8,800—19,500		
Serdang/Munchong	2,700—7,400	270—1,200	1,350—13,500	170—1,700
Batu Anam	3,400—11,500	270—1,000	5,400—9,400	
Malacca	6,740—13,500	400—1,700	1,000—17,000	400—1,900
Seremban	3,400—8,100	880—1,700	4,700—12,100	800—3,200
Minimal requirement from soil nutrient reserves	650[a,b]—950[b]		950[c]—1,250[b]	370[b]

[a] Estimate of symbiotic nitrogen fixation included
[b] *Based on fertiliser schedule using Mixture Magnesium M and* C_2
[c] Based on fertiliser schedule using Mixture Magnesium X and Y

quoted. These figures are calculated on the basis that such a volume of soil will weigh 6.74×10^6 kg per hectare (equivalent to 6×10^6 lb per acre) and using the concentration data appertaining to the 0—12 in. depth. The depth of 18 inches has been chosen because observations on root development indicate that the rubber tree absorbs most of its nutrients from this zone. In *Table 4* an estimate has been provided of the minimum quantities of nitrogen, potassium and magnesium that the planted trees must derive from the soil, by subtracting the amount of nutrients supplied as fertiliser from the total nutrient requirement of the tree at the thirty-three-year-old stage.

TABLE 5. NUTRIENT CONCENTRATIONS IN RUBBER AND NUTRIENT REMOVAL IN KG PER HA PER YEAR ASSUMING YIELD OF 1700 KG PER HA PER YEAR

(The concentration data obtained from unpublished work relating to clones PB86, RRIM 501, Gl 1, Tjir 1 and PR 107 growing on different soil types)

Element	%wt. on total solids	Kg per ha per year
Nitrogen	0.70	11.9
Potassium	0.60	10.2
Magnesium	0.15	2.5
Phosphorus	0.20	3.4

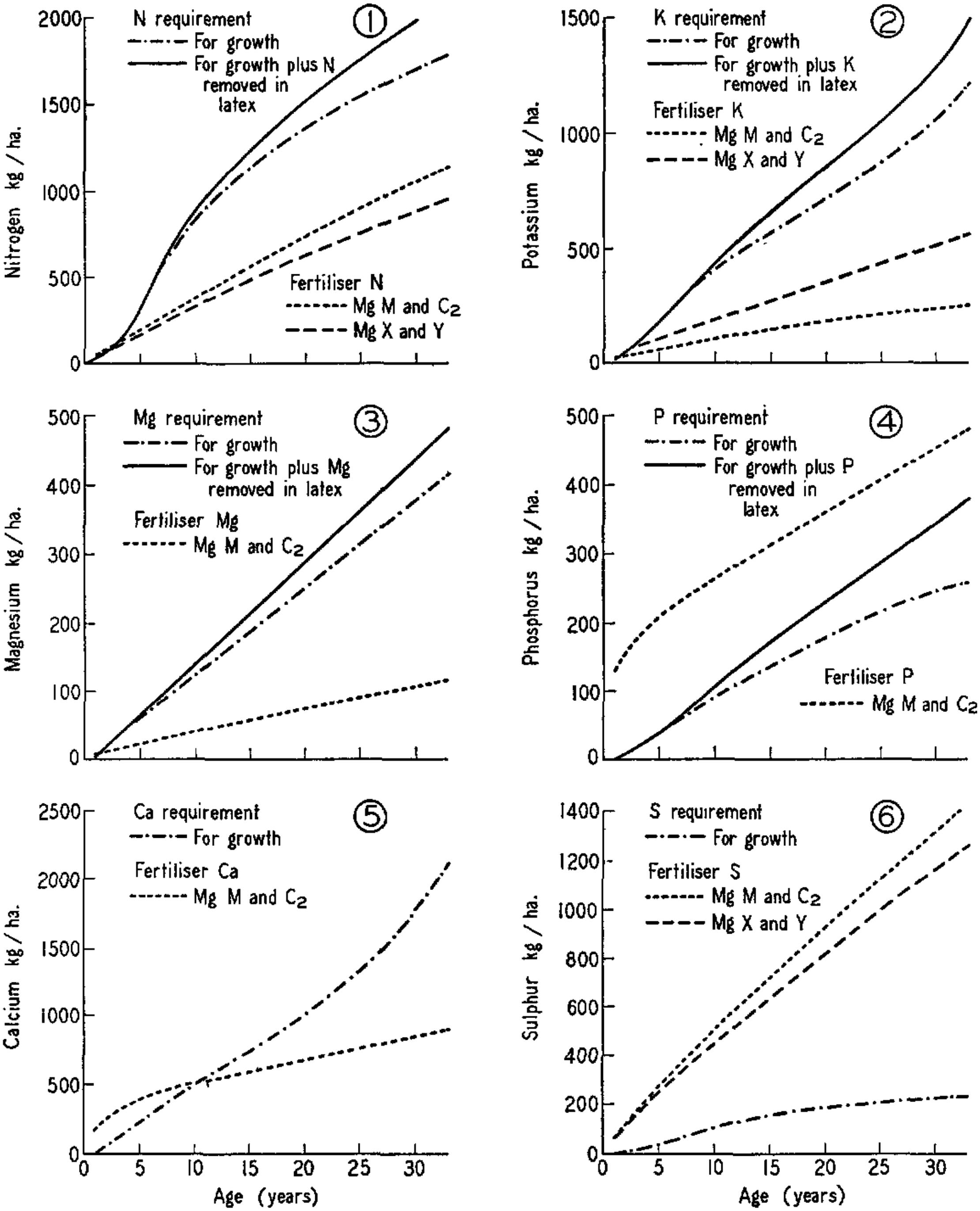
TREE NUTRIENT REQUIREMENT AND FERTILISER APPLICATION

The nitrogen, phosphorus, potassium, magnesium, calcium and sulphur contents of trees from one to thirty-three years of age are shown in *Figures 1—6*, the data being taken from SHORROCKS (1965a): for simplification smooth curves have been drawn. The amounts of nutrients removed in latex have been added to the tree nutrient content to give a better estimate of nutrient requirements, assuming an average yield of 1,700 kg per hectare per annum (approximately 1,500 lb per acre per annum) commencing in the sixth year, and with a latex nutrient composition as shown in *Table 5*. The amounts of each nutrient supplied by normal fertiliser mixtures containing ammonium sulphate, potassium chloride, rock phosphate and kieserite, used in Malayan rubber cultivation over the life of the planting, are also included in *Figures 1—6*. For this purpose two fertiliser schedules have been quoted: one designed for use on inland loams and clay loams, using Mixtures Magnesium M and C_2, and the other on inland sands and sandy loam soils, using Mixtures Magnesium X and Y, the fertilisers for each schedule differing principally in their content of potassium chloride (*Table 6*). The fertiliser schedule during immaturity is that given by the RUBBER RESEARCH INSTITUTE OF MALAYA (1963a) and for mature rubber it is based on annual application throughout the life of the planting of 2 lb per tree of Mixture Magnesium C_2 or Magnesium Y fertiliser (SHORROCKS, 1964).

Despite the fact that in these calculations a high estimate of yield has been taken, it can be seen from *Figures 1, 2, 3* and *4* that the amounts of nutrient removed in the latex are small relative to the nutrient requirements for growth. With normal fertiliser dressings, insufficient nitrogen, potassium and magnesium is applied as fertiliser even to meet the large growth requirement for the nutrients, and

TABLE 6. PERCENTAGE COMPOSITION OF FERTILISER MIXTURES

Mixture	Ammonium sulphate	Christmas Island phosphate	Potassium chloride	Kieserite
Magnesium M	42	45	5	8
Magnesium X	40	40	12	8
Magnesium Y	51	29	12	8
Magnesium C_2	62	24	6	8



Figures 1—6. Tree nutrient requirement and nutrient applied as fertiliser (cumulative totals). 1. Nitrogen. 2. Potassium. 3. Magnesium. 4. Phosphorus. 5. Calcium. 6. Sulphur.

therefore it does not appear logical to relate fertiliser nutrient supply to the yield and nutrient drain in latex, as has often been suggested. It would appear preferable to relate the fertiliser requirement to the growth of the tree, always of course with due reference to any particular effect the applied nutrients may have on yield or on the physical properties of the latex.

Nitrogen. On the assumption that all the applied nitrogen will be utilised, sufficient fertiliser nitrogen is applied in the normal schedule during the first three years of growth to meet the trees' requirement. Thereafter, the amount of nitrogen applied as fertiliser is insufficient and, at thirty-three years, only approximately half of the total nitrogen requirement will have been provided by fertiliser application (*Figure 1*). The assumption, made here and below, that all the applied fertiliser nutrient may be utilised, is obviously not valid as only a proportion will be absorbed: however the assumption is necessary as a first approximation to provide a basis for comparing applied nutrients with those taken up by the tree, in the absence of quantitative data regarding the efficiency of fertiliser utilisation.

In the early years after planting, considerable quantities of nitrogen are provided by nitrogen fixation carried out by the leguminous covers normally planted between the rows of trees, (WATSON, 1957; WATSON *et al.*, 1963, 1964a, 1964b). Although it is not possible to evaluate the precise amount of nitrogen fixed, for the present purposes it is conservatively estimated that something in the region of 300 kg per hectare of nitrogen (equivalent to 1,500 kg per hectare of ammonium sulphate) is fixed by the legumes during their years of active growth. This nitrogen, together with the nitrogen supplied by normal fertilisers, would be sufficient if completely utilised to meet the trees' nitrogen requirement up to about the seventh year. During the period of rapid return of nitrogen to the soil from the legumes as they die back, from approximately the third to the fifth year, it is likely in fact that the total nitrogen supply will exceed tree requirement and there will be losses of nitrogen by leaching of excess nitrate ions. The high return of nitrogen to the soil by legume covers at this time increases the nitrogen status of the tree and this is likely to exert a marked and persistent effect upon the nitrogen economy of the planting for an extended period.

It seems that when the nitrogen deposited in rain, approximately 20 kg per hectare per annum, is also considered together with the other nitrogen sources, the total amounts of nitrogen added to the soil should be sufficient to meet the nitrogen requirement of the planting during its entire life.

Potassium. On the assumption that all the applied fertiliser potassium is utilised by the tree, sufficient potassium to meet the trees' requirement is supplied by the low potassium content fertilisers only in the first year of growth, and by fertilisers with a high potassium content during approximately the first four years of growth. Thereafter potassium derived from fertiliser amounts to approximately 20% and 40% of the total tree potassium requirement in the case of the low and high potassium content fertilisers respectively (*Figure 2*). The quantity of potassium removed in latex is only slightly less than that supplied by the low potassium content fertiliser. According to the data presented above, approximately 400 kg per hectare of potassium may be deposited in rainfall throughout the life of the planting: this is a considerable amount, being larger than that supplied by the low potassium content fertiliser. If this potassium is added to that supplied by the high potassium content fertilisers the total would be sufficient to meet approximately 60% of the total requirement of the planting.

Magnesium. The amounts of magnesium supplied by fertiliser applications would be sufficient to meet the trees' requirement during the first two years of growth provided that all the applied nutrient was utilised by the tree; thereafter the quantities applied would be sufficient to meet approximately only 25% of the trees' requirement (*Figure 3*). The magnesium content of rainfall is small, only about 3 kg per hectare per annum, but it is nearly equal to the amount of fertiliser magnesium applied annually to the planting, and both exceed the quantities removed in latex.

Phosphorus. Rock phosphate, the phosphatic fertiliser commonly used in Malayan rubber cultivation, is applied in the planting hole at the rate of 4 oz per point, and also to the leguminous covers in the inter-row areas during the first few years of growth at the total rate of approximately 4 cwt per acre; these quantities have been included in the estimate of applied phosphorus.

About half the phosphorus given to one planting is applied in the first six years and in contrast to the situation for nitrogen, potassium and magnesium, the quantity considerably exceeds that required by the tree (*Figure 4*). However, only a small proportion of the phosphate applied as rock phosphate is available for uptake by the tree at any one time, considerable amounts of phosphate being unavailable and only slowly released over a prolonged period (OWEN, 1947; 1953a); for this reason relatively large rock phosphate applications are required to maintain sufficient phosphate available in the soil for tree uptake at any one time.

Calcium. Considerable amounts of calcium are supplied by the rock phosphate incorporated in the normal fertiliser mixtures or applied directly to the covers, and it can be seen from *Figure 5* that more calcium is supplied during the first ten years of growth of the tree than is actually required by the tree over that time. Thereafter the fertiliser calcium is insufficient to meet the tree requirement, and although it is possible that the data presented here slightly overestimate the calcium requirement of the tree owing to the deposition of large amounts of calcium in the bark (SHORROCKS, 1965a), the generally low levels of soil calcium and the leaching of calcium through the soil (WATSON, 1964) indicate that additional sources may be required. Only very small amounts of calcium are found in latex (approximately 0.03 kg in 1,500 kg of rubber) and accordingly no estimate of calcium removed in latex has been included in *Figure 5*.

Sulphur. The ammonium sulphate and to a lesser extent the kieserite included in the normal fertilisers applied to rubber provide considerable quantities of sulphur which greatly exceed the requirement of the trees at all stages of growth (*Figure 6*). The sulphur supplied by kieserite alone, although only about 12% of the total sulphur supplied by normal fertiliser mixtures, is nearly sufficient to meet the trees' sulphur requirement. Thus if ammonium sulphate were not applied, the continued use of kieserite at current rates of application would probably maintain the sulphur status of the trees at a satisfactory level. Furthermore, as the sulphate ion does not leach rapidly through the latosolic soils of Malaya (BOLTON, 1963), it seems unlikely that sulphur deficiency will occur in rubber which at one time or another has received regular dressings of ammonium sulphate.

DISCUSSION

In the following discussion it is to be understood that fertilisers are required only when an economic response can be confidently predicted. A requirement is not considered to exist simply to replace nutrients removed from the soil-vegetation system. Such replenishment of soil nutrients may seem a sound agricultural principal and where soil nutrient reserves are low, will very probably result in economic responses. However, it is possible for a soil to contain sufficient nutrients for optimal growth and yield over many years; on such soils there will be no response to the application by fertiliser of nutrients in good supply and it would be uneconomic to apply fertiliser just to replace nutrients lost or removed from the soil-vegetation system.

The need for fertiliser applications to supplement the soil supply of available nutrients in order to promote good growth of young rubber on inland soil types has been demonstrated by many fertiliser experiments carried out over the last thirty years (AKHURST, 1937; HAINES AND CROWTHER, 1940; AKHURST AND OWEN, 1950; BOLTON, 1964a) and manuring schedules are available covering the immature phase (RUBBER RESEARCH INSTITUTE OF

MALAYA, 1953b; 1958; 1963a). As the detrimental effects of a deficiency may be felt over many years, it is considered advisable to apply generous fertiliser applications to immature rubber, on the conservative principle of ensuring satisfactory establishment of the young rubber: thus on the better soil types the scheduled rates of fertiliser application may supply rather more nutrients than are immediately required.

Comparatively few experiments have been carried out on mature rubber; OWEN *et al.* (1957) and BOLTON (1960), reported results from experiments in jungle plantings started during the immature phase, but from their results it is not easy to distinguish clearly between the effects of fertilisers applied during maturity and immaturity. The indications were, however, that on the average Malayan soil types planted from jungle, responses to fertilisers applied during maturity are likely to be small although economic. However, in replanted rubber the case is likely to be quite different: as indicated above, soil nutrient reserves are likely to be depleted at replanting and nutrient deficiencies must be expected as the second generation of rubber draws further on the soil nutrient reserves. In experiments sited on soils known to be deficient in nutrients, substantial and economic responses have been obtained from the application of fertiliser to mature rubber, as reported by HAINES AND GUEST (1936) in the case of nitrogen deficiency, by BOLTON AND SHORROCKS (1961) in the case of magnesium deficiency, and by the RUBBER RESEARCH INSTITUTE OF MALAYA (1964b) in the case of potassium deficiency.

Despite a lack of firm data regarding the economics of fertilisers applied to mature rubber in general, it has been considered good practice to apply, on all but the fertile coastal alluvial clay soils, annual dressings of the order of 2 lb per tree of a mixed fertiliser containing nitrogen, phosphorus, potassium and magnesium, in order to maintain the general condition and yield level of the trees (RUBBER RESEARCH INSTITUTE OF MALAYA, 1953a). However, owing to the wide variation in nutrient status of Malayan soils (*Table 3*) and the relation discussed below between the nutrient requirement of the tree and the soil nutrient content, it is evident that there is considerable scope for improvement in fertiliser utilisation particularly on mature rubber. In the following sections suggestions for such improvements are outlined.

Nitrogen. From *Figure 1* the amount of nitrogen applied as fertiliser during the first few years after planting appears to be sufficient; where vigorous legume covers have been grown it seems that the application of fertiliser nitrogen could be discontinued, at least during the period of dieback of the legumes from the third to the fifth year (WATSON, 1964), without any detriment to growth and possibly with benefit in plantings with material susceptible to wind damage.

It is not possible to assess easily from the levels of total soil nitrogen the amounts that are likely to become available for tree uptake in the course of time and hence to distinguish the soils on which nitrogen application during maturity can either be reduced or stopped. From *Table 4* it can be seen that the reserves of nitrogen in all soils greatly exceed the nitrogen required by a planting. Much of this nitrogen is in an unavailable form, and when it is considered that responses to nitrogenous fertilisers are frequently obtained on the Selangor series soils (PUSHPARAJAH, 1964) which have a comparatively high nitrogen status, it seems that there is likely to be a steady requirement for nitrogen fertiliser, despite the relatively large amounts of nitrogen that are in cycle. The most satisfactory guide to determine the requirement for nitrogenous fertiliser is leaf analysis; only where analysis shows trees to be of high nitrogen status, as assessed by leaf sampling at the end of the year (SHORROCKS, 1965b), should nitrogen application be withheld, to be renewed when a fall in leaf nitrogen status is detected.

Phosphorus. The fact that the phosphorus content of most Malayan soils is low and that good responses by both rubber and covers to the application of rock phosphate are obtained during immaturity, clearly indicates that no reduction in the earlier applications of rock phosphate should in general be considered. Exceptions are on the Kuantan series and Selangor series soils, both of which have large reserves of apparently easily available phosphorus (RUBBER RESEARCH INSTITUTE OF MALAYA, 1964c) and on which rubber is unlikely to respond to phosphate applications. With all other soils, and particularly those of the Batu Anam, Serdang, Munchong and Malacca series, whose total contents are lower than the phosphorus requirement of one planting, the generous application of rock phosphate to both rubber and cover in the immature phase is essential; such applications will be in excess of the trees' immediate requirement but will build up a reserve of soil phosphate which will slowly release phosphorus for uptake by the mature rubber over an ex-extended period of time.

There is little evidence of any beneficial effects of rock phosphate applied during maturity to rubber that has received normal applications of rock phosphate during immaturity. According to the work of OWEN (1953b), later confirmed by BOLTON (1960; 1961), responses to phosphate are not likely when available soil phosphorus exceeds 11 p.p.m., and experimental data indicate that this level is likely to be exceeded in areas that have received the normal dressings of rock phosphate during immaturity (BOLTON, 1961, 1964a). It seems likely that phosphate applications to mature trees will be necessary only where leaf analysis indicates a low phosphorus status, and where this is confirmed by soil analysis.

Potassium. It seems evident from previous considerations that after the first few years from planting the amount of potassium supplied according to present fertiliser schedules falls appreciably short of the total requirement of the tree. Potassium deficiency symptoms are frequently observed in mature rubber and it seems likely that more generous use of potassium fertilisers will be required in the future.

The potassium content of Malayan soils varies over a wide range; those soils derived from impoverished alluvial material, such as the Ulu Tiram, Holyrood, Chemor and Sungei Buloh series, together with the sedentary Rengam and Kuantan series, derived respectively from granite and basalt, would appear to be deficient, while those derived *in situ* from sedimentary material, the Malacca, Seremban and Batu Anam series, generally have an adequate potassium supply. HAINES AND CROWTHER (1940) could detect no response by young rubber to potassium on the Batu Anam soils, but AKHURST AND OWEN (1950) and BOLTON (1960), studying soils derived from granite and others of low potassium status, found definite responses. In some instances depressive effects of potassium, particularly in the absence of nitrogenous and magnesium fertilisers have been recorded (BOLTON, 1964b), but this may be due to potassium/magnesium antagonism rather than to any direct adverse effect of the potassium.

There thus appears to be a good case for discrimination in the utilisation of the potassium fertilisers, and in *Figure 7(a)* an attempt has been made to relate the potassium concentration in the soil (together with, in one relationship, the rainfall potassium) and the amounts of potassium chloride which should be added annually to ensure good growth and yield. The calculations are based on the principle that fertiliser potassium should be provided over the life of the planting in quantities which, if added to the potassium content of the top 18 inches of the soil, would ensure that the total potassium would be equal to twice the potassium requirement of the planting (i.e. 3,000 kg per ha). Thus for example where soil content is 3,000 kg per ha (equivalent to 445 p.p.m. K) no fertiliser potassium will be required; but if the soil potassium content is 1,000 kg per ha (equivalent to 150 p.p.m. K) 2,000 kg per ha of potassium per planting will be required, that is an annual application of 134 kg per ha potassium chloride (49.8 %K) over a period of thirty years. If rainfall potassium (400 kg per ha per planting) is considered it is found that no potassium fertiliser is required when the soil contains 385 p.p.m. K (*Figure 7(a)*).

The principle of taking twice the requirement of a planting was somewhat arbitrarily chosen from a series of calculations because it roughly fitted the available facts about the potassium content of soils and the likely responses to potassium chloride. According to studies relating leaf potassium to total soil potassium (GUHA, 1964) satisfactory leaf potassium concentrations can, in general, be expected when soil potassium is over 500 p.p.m. BOLTON (1964a) found that immature rubber showed positive responses to potassium fertilisers when the potassium concentration of the soil was 120 p.p.m. K and strong indications of positive responses when the potassium concentration of the soil was 176 p.p.m. K. The use of a potassium concentration of either 385 or 445 p.p.m. K in *Figure 7*(*a*) thus appears to be high according to BOLTON (1964a) and slightly low according to GUHA (1964).

It should be emphasised that this suggested method of assessing the requirement for potassium, and also that for magnesium discussed below, is put forward only as a tentative proposal based on present soil and leaf analytical evidence and because of the difficulty of obtaining adequate field experimental data relating soils and their nutrient status with tree performance. No consideration of the physicochemical nature of the sources of potassium and magnesium in the soil has been included, nor of availability of nutrients according to soil physical conditions; as relevant soil and field experimental data build up, the method will doubtless be improved upon.

The annual rates of potassium chloride application shown in *Figure 7*(*a*) have been calculated on the basis of applications to be made over a period of thirty years. If the appropriate rates of potassium chloride application are maintained up to say the twentieth year of a planting and good growth and satisfactory

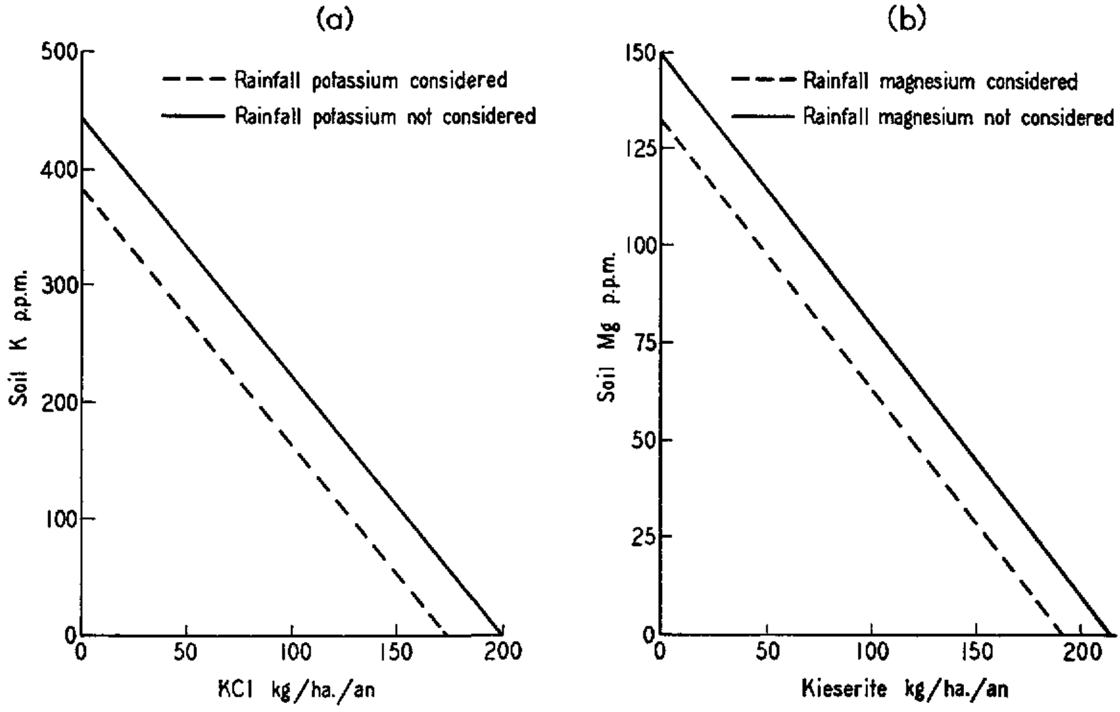


Figure 7(*a*). *Theoretical relationship between soil potassium* (*acid extractable*) *and the annual rate of potassium chloride application required for good growth of rubber.* (*b*). *The same relationship for soil magnesium* (*acid extractable*) *and kieserite.*

levels of leaf potassium content have been maintained, it is unlikely that further application of potassium fertilisers will be of economic benefit during the last ten or even fifteen years of growth.

Magnesium. Magnesium is like potassium in that fertiliser and rainfall supplies fall far short of the total tree requirement, except in the first few years after planting. The frequency with which magnesium deficiency has been encountered confirms that higher levels of supply will be required than in the past (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963a).

The magnesium content of Malayan soils varies over a wide range; reserves are low on many of the Rengam, Holyrood and Chemor series soils, and some related to the Malacca series, whilst the Kuantan and Seremban series are likely to contain adequate supplies. At the same time the potassium content of some of the Seremban and Malacca series may be sufficiently high to depress magnesium uptake and there is thus scope for discriminatory use of magnesium fertilisers.

The amounts of kieserite required to raise the soil magnesium level to twice that of the tree requirement have been related to the soil magnesium content in *Figure 7(b)*, the method of calculation being similar to that described above for potassium. The choice of twice the tree magnesium requirement is entirely arbitrary, since there is no experimental evidence on soil magnesium levels to use as a guide.

It is seen from *Figure 7(b)* that if the soil magnesium content is 150 p.p.m. Mg or above (or 130 p.p.m. if rainfall magnesium is considered) a requirement for magnesium fertilisers would not be expected, and this conclusion fits the known performance of trees on the soil types quoted in *Table 3* reasonably well.

CONCLUSIONS AND RECOMMENDATIONS FOR MANURING

Immature rubber. It is important that optimal growing conditions are maintained for immature rubber and it is recommended that the fertiliser programme in current use for the various soil types (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963a) be followed: apart from the possibility of withholding fertiliser applications during the period of dieback of vigorous legume covers the programmes should only be modified in the event of a deficiency being diagnosed visually or by leaf analysis. Modifications may entail increasing the rate of application of the fertiliser already employed, or the use of additional special fertiliser applications according to the rates given by SHORROCKS (1964).

Increasing the rate of application of the fertiliser mixture already used would only be appropriate in the case of nitrogen and phosphorus deficiencies, as the fertilisers in common use contain relatively large quantities of nitrogen and phosphorus and only small quantities of potassium and magnesium, too small to cause large increases in either the potassium or magnesium status of the trees.

In the case of potassium and magnesium, deficiencies should be corrected by applying dressings of the appropriate straight fertiliser without changing the routine fertiliser programme. Ideally the need for such corrective applications should be checked by leaf and soil analysis; a fertiliser programme not only for immaturity but also for maturity could be drawn up after assessing the amounts of either potassium chloride or kieserite that should be applied annually on the basis of the considerations discussed in the present paper.

Mature rubber. There is considerably greater scope for discrimination in fertiliser usage with mature rubber than with immature rubber. The data on tree and soil nutrient content indicate that while some soils contain adequate nutrient reserves to sustain satisfactory tree growth, there are many on which deficiencies are likely to develop as their nutrient reserves are depleted by immobilisation in the tree. Optimum efficiency of fertiliser usage seems likely to be ensured only with the use of soil and leaf analysis.

In general, current levels of nitrogen applications appear to be adequate and accordingly an annual application of approximately 160 kg per ha per annum of ammonium sulphate is recommended for all inland soils, except possibly the Kuantan series and for those coastal alluvial soils known to be high in nitrogen. Where growth is good and where the leaf nitrogen status is high (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963b) it is suggested that nitrogen applications be withheld until further leaf analysis indicates a requirement.

Well grown mature trees are not likely to respond to phosphate applications on the Selangor or Kuantan Series soils, or on other soils where the phosphate level has been built up by applications of rock phosphate during immaturity; under such conditions it is suggested that phosphate applications should be stopped when the trees come into tapping. Rock phosphate should be applied to mature rubber when little or no phosphate has been applied during immaturity and maintenance dressings of 60 kg per ha, similar to those currently employed, are suggested; when a requirement is indicated by leaf analysis the levels given by SHORROCKS (1964) would be more appropriate.

Whenever possible the level of potassium and magnesium applications should be based on soil analysis, as discussed here, in order to provide a long term solution. It seems likely, as shown in *Figure 7(a)*, that on soils of low potassium status (with about 100 p.p.m. acid-extractable K) annual maintenance dressings of 150 kg per ha potassium chloride will be required; however, on better soils with about 300 p.p.m. K, 50 kg per ha should be sufficient. Similarly for magnesium it is suggested that on soils with about 50 p.p.m. acid-extractable Mg annual maintenance dressings of 150 kg per ha kieserite should be applied, and that on the better soils with 100 p.p.m. Mg, 50 kg per ha should be satisfactory. In view of the tentative basis on which the above levels of potassium and magnesium are recommended, their suitability under different conditions should, in the first instance, be confirmed by leaf analysis. When an immediate requirement for potassium or magnesium is diagnosed visually or by leaf analysis it is recommended that it should be corrected by special fertiliser applications at the rates given by SHORROCKS (1964).

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REFERENCES

AKHURST, C. G. (1937) Manuring experiment on young rubber trees—R.R.I.M. Experimental Station—Block 6. *J. Rubb. Res. Inst. Malaya* **8**, 46.

AKHURST, C. G. AND OWEN, G. (1950) Manuring experiment on young rubber trees I. Effect of fertilisers on growth. *J. Rubb. Res. Inst. Malaya* **12**, 167.

ALLISON, F. E. (1955) The enigma of soil nitrogen balance sheets. *Advanc. Agron.* **7**, 213.

BOLTON, J. (1960) The response of *Hevea* to fertilisers on a sandy latosol. *J. Rubb. Res. Inst. Malaya* **16**, 178.

BOLTON, J. (1961) The effect of fertilisers on pH and the exchangeable cations of some Malayan soils. *Proc. Nat. Rubb. Res. Conf., Kuala Lumpur, 1960*, 70.

BOLTON, J. (1963) A study of the leaching of commonly used fertilisers on Malayan latosols used for the cultivation of *Hevea brasiliensis*. Thesis submitted for the degree of Master of Science, University of Leeds.

BOLTON, J. (1964a) The response of immature *Hevea brasiliensis* to fertilisers in Malaya I. Experiments on shale derived soils. *J. Rubb. Res. Inst. Malaya* **18**, 67.

BOLTON, J. (1964b) The manuring and cultivation of *Hevea brasiliensis*. *J. Sci. Fd. Agric.* **15**, 1.

BOLTON, J. AND SHORROCKS, V. M. (1961) The effect of magnesium limestone and other fertilisers on a mature planting of *Hevea brasiliensis*. *J. Rubb. Res. Inst. Malaya* **17**, 31.

GUHA, M. M. (1964) Unpublished data. R.R.I.M.

HAINES, W. B. AND GUEST, E. (1936) Recent experiments on manuring *Hevea* and their bearing on estate practice. *Emp. J. expt. Agric.* **4**, 300.

HAINES, W.B. AND CROWTHER, E. M. (1940) Manuring *Hevea* III. Results on young buddings in British Malaya. *Emp. J. expt. Agric.* **8**, 169.

NYE, P. H. AND GREENLAND, D. J. (1960) The soil under shifting cultivation. *Tech. Commun.* No. 51, *Bur. Soil Sci., Harpenden.*

OWEN, G. (1947) Retention of phosphates by Malayan soil. The nature of phosphate retention in different soil types. *J. Rubb. Res. Inst. Malaya* **12**, 1.

OWEN, G. (1953a) Studies on the phosphate problem in Malayan soils. *J. Rub. Res. Inst. Malaya* **14**, 121.

OWEN, G. (1953b) Determination of available nutrients in Malayan soils. *J. Rubb. Res. Inst. Malaya* **14**, 109.

OWEN, G., WESTGARTH, D. R. AND IYER, G. C. (1957) Manuring *Hevea*: Effects of fertilisers on growth and yield of mature rubber trees. *J. Rubb. Res. Inst. Malaya* **15**, 29.

PUSHPARAJAH, E. (1964) Response of immature *Hevea brasiliensis* to fertilisers on three experiments sited on alluvial soils of the West coast of Malaya. *Research Archives of the R.R.I.M.* Document No. 32.

RUBBER RESEARCH INSTITUTE OF MALAYA (1953a) Yield maintenance of mature rubber trees. *R.R.I. Plant. Bull.* No. *8*, *95*.

RUBBER RESEARCH INSTITUTE OF MALAYA (1953b) Fertiliser treatment and maintenance for young replantings. *R.R.I. Plant. Bull.* No. 9, 120.

RUBBER RESEARCH INSTITUTE OF MALAYA (1958) *Manuring programme for young replantings R.R.I. Plant. Bull.* No. 35, 46.

RUBBER RESEARCH INSTITUTE OF MALAYA (1963a) Revised manuring programme for young replantings. *R.R.I. Plant. Bull.* No. 67, 79.

RUBBER RESEARCH INSTITUTE OF MALAYA (1963b) *Rep. Rubb. Res. Inst. Malaya 1962*, 21.

RUBBER RESEARCH INSTITUTE OF MALAYA (1964a) The use of soil and leaf analysis in assessing fertiliser requirements. *R.R.I. Plant. Bull.* No. 71, 41.

RUBBER RESEARCH INSTITUTE OF MALAYA (1964b) *Rep. Rubb. Res. Inst. Malaya 1963*, 17.

RUBBER RESEARCH INSTITUTE OF MALAYA (1964c) *Rep. Rubb. Res. Inst. Malaya 1963*, 23.

SHORROCKS, V. M. (1964) *Mineral Deficiencies in Hevea and Associated Cover Plants.* Kuala Lumpur: Rubber Research Institute of Malaya.

SHORROCKS, V. M. (1965a) Mineral nutrition, growth and nutrient cycle of Hevea brasiliensis I. Growth and nutrient content. *J. Rubb. Res. Inst. Malaya.* **19**, 32.

SHORROCKS, V. M. (1965b) Leaf analysis as a guide to the nutrition of *Hevea brasiliensis* VI. Variations in leaf nutrient composition with age of leaf and with time. *J. Rubb. Res. Inst. Malaya* **19**, 1.

WATSON, G. A. (1957) Nitrogen fixation by *Centrosema pubescens. J. Rubb. Res. Inst. Malaya* **15**, 168.

WATSON, G. A. (1964) Maintenance of soil fertility in the permanent cultivation of *Hevea brasiliensis* in Malaya. *Outlook on Agric.* **4**, 103.

WATSON, G. A. WONG PHUI WENG AND NARAYANAN, R. (1963) A supplement to the paper: 'Effects of cover plants on soil nutrient status and on growth of *Hevea* IV. Leguminous creepers compared with grasses, *Mikania cordata* and mixed indigenous covers on four soil types'. *Research Archives of the R.R.I.M.* Document No. 22.

WATSON, G. A. WONG PHUI WENG AND NARAYANAN, R. (1964a) Effects of cover plants on soil nutrient status and on growth of *Hevea* III. A comparison of leguminous creepers with grasses and *Mikania cordata. J. Rubb. Res. Inst. Malaya* **18**, 80.

WATSON, G. A., WONG PHUI WENG AND NARAYANAN, R. (1964b) Effects of cover plants on soil nutrient status and growth of *Hevea* IV. Leguminous creepers compared with grasses, *Mikania cordata* and mixed indigenous covers on four soil types. *J. Rubb. Res. Inst. Malaya* **18**, *123*.

WATSON, G. A., WONG PHUI WENG AND NARAYANAN, R. (1964c) Effects of cover plants on soil nutrient status and on growth of *Hevea* V. Loss of nitrate-nitrogen and of cations under bare soil conditions. A progress report on results from a small scale trial. *J. Rubb. Res. Inst. Malaya* **18**, 161.