Mineral Nutrition, Growth and Nutrient Cycle of Hevea brasiliensis I. Growth and Nutrient Content

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A study of the growth and nutrient content of Hevea brasiliensis *trees varying in age from one to thirty-three years has been carried out, by weighing entire trees and analysing samples of roots, trunk, branches and leaves for both the major and minor nutrients. The rate of growth of* Hevea *appears to be of the same order as that reported for secondary tropical forest, and also for oil palms. The nutrient content data are discussed briefly in relation to current fertiliser practice and the need for greater discrimination in fertiliser use.*

Information regarding the growth and total nutrient content of a plant at different stages in its growth cycle is a basic requirement for the assessment of nutritional problems but has not so far been available for *Hevea brasiliensis*. A need for information of this kind was appreciated by DYCK (1939) who reported data on the nutrient content of one tree, approximately thirty-five years old, with a dry weight of 7911 lb. Other workers have since reported further tree dry weight data (CONSTABLE, 1955; BEAUFILS AND NGUYEN, 1957 and OTOUL, 1960), but no detailed chemical analysis of trees of different ages has been reported. This paper presents the results of a study covering the main period of economic usefulness of the tree, in which trees ranging from one to thirty-three years old have been weighed and analysed for both the major and minor nutrients. The felling, weighing and sampling of entire trees is laborious and time-consuming, particularly with trees older than ten years, and this necessarily limited the number of trees that could be weighed and thereby the scope of the work.

However, data have been accumulated from which deductions can be made which are applicable to many aspects of the growth and the nutrition of *Hevea*. To simplify presentation, only the primary data are considered in this paper; they indicate the general pattern of growth and total nutrient content of the average tree at different stages of growth. Subsequent papers will deal with relationships that exist between tree girth, total growth and yield of rubber, and the differences in the pattern of growth due to planting material and to soil conditions.

METHODS

The investigation was restricted to clones RRIM 501 and Tjir 1 sampled in 1958, except in the case of four-year-old trees of clones PB 86, LCB 1320 and GT 1 which were sampled in an N, P, K, Mg manuring experiment at the time of thinning in 1962. Details of the sampled trees are given in *Table 1*.

The data on the four-year-old PB 86, LCB 1320 and GT 1 trees are mean values calculated from all trees of each clone, the trees being drawn evenly from all manuring treatments. The investigation of the growth of these three clones was carried out both to determine the effects of fertiliser treatment on tree growth and to study the relationship between girth and growth. The other trees, except the oldest, had been regularly manured with NPK mixtures, the twenty-four-year-old trees had received fertiliser only during the latter twelve years of growth, while the thirty-three-year-old trees had received no fertiliser from the thirteenth to eighteenth year. The sampled trees were selected as showing average growth under normal field conditions and the

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COMMUNICATION 383

TABLE 1. DETAILS OF THE TREES

Age, years	Clone	Number of trees sampled	Girth, in. (at 60 in.)	Height[b], ft	Trees per acre	Trees per hectare	Soil series [a]	Month of sampling	Previous history
1	RRIM 501	2	4.7	15	180	445	Sungei Buloh	March	Jungle
2	RRIM 501	2	9.1	23	180	445	Sungei Buloh	April	Jungle
3	RRIM 501	2	11.2	24	180	445	related to Malacca	March	Jungle
4	PB 86	80	9.6	—	160	395	Rengam	February	Jungle
4	GT 1	80	13.3	—	160	395	Rengam	February	Jungle
4	LCB 1320	77	14.7	—	160	395	Rengam	February	Jungle
4	RRIM 501	1	15.7	—	165	408	related to Malacca	May	Jungle with period of food cropping between clearing and planting
5	RRIM 501	1	19.1	43	150	371	related to Malacca	May	Jungle with period of food cropping between clearing and planting
6	RRIM 501	1	20.5	—	140	346	related to Malacca	July	Jungle with period of food cropping between clearing and planting
8	RRIM 501	1	26.4	—	130	321	related to Malacca	July	Jungle with period of food cropping between clearing and planting
10	RRIM 501	3	33.8	62	120	296	related to Malacca	June	Jungle with period of food cropping between clearing and planting
11	Tjir 1	3	31.0	66	120	296	Sungei Buloh	June	Rubber
24	RRIM 501	3	40.2	76	100	247	Serdang	June	Jungle
33	Tjir 1	4	46.2	79	108	267	Sungei Buloh	February	Jungle
33[c]	Tjir 1	1	71.5	80	108	267	Sungei Buloh	February	Jungle

[a] Soil series according to OWEN (1951)

[b] Where no figures are given the height was not measured.

[c] Tree not tapped in stand of tapped trees

girth data quoted in *Table 1* confirm that they can be regarded as typical for the various ages considered; the periods of immaturity of the fields in which the trees were sampled ranged from approximately five to seven years. It is concluded that the sampled trees provide an adequate representation of the growth that can be expected during the economic life of *Hevea*. Confirmatory tree weight data will be reported in the study on the relationship between girth and growth.

Trees were selected for sampling in which there was a clear distinction between the main stem and the branching system above the fork, thus enabling a standard trunk to be sampled on all trees; the length of trunk, cut just above the union and at the junction of the first order branches, varied from 9 to 11 feet on the trees which were one to eight years old.

Sampling Procedure

The trees were divided into five morphological units, namely

1. roots; the tap and the lateral roots being considered together
2. the trunk including the collar or union; the main branches being cut off from the trunk at the fork
3. green branches; which largely represent the current years' branch growth
4. all remaining branches
5. leaves; consisting of laminae and petioles.

For the trees one to eight years old, a detailed separation of the different morphological units was carried out: except for the four-year-old trees of clones PB 86, LCB 1320 and GT 1, where the roots were not sampled, the tap and lateral roots were dealt with separately, the fine fibrous feeding roots being collected as far as possible and weighed together with the lateral roots. The collar and trunk were also sampled separately, while the branches including the green branches were separated according to branch order, on the basis of the first order branches arising from the trunk, second order branches from the first order branches etc. The leaves were separated according to the order of the branch on which they were borne. The data relating to the detailed sampling, from which the current summarised and simplified presentation has been derived, are given in a *Supplement* to this paper (SHORROCKS, 1964).

Less detailed sampling and separation was carried out on the trees older than eight years, the trees being divided in the field into the five morphological units described above, with the roots left unsampled.

Total fresh weights were measured in the field: samples were taken for dry weight determination and for chemical analysis, to enable the dry weight and nutrient content of the entire tree to be calculated. Preliminary investigations on branch sampling for analysis had shown no gradation in the nitrogen, phosphorus, potassium, magnesium, calcium or manganese concentrations in the wood along a branch. In the bark a gradation was found: the calcium and manganese concentrations, were lower and the nitrogen concentrations were higher at the distal rather than the proximal end of a branch, results which are similar to those reported by BOLLE-JONES (1957) for bark on the trunk. To allow for the variation three samples were taken from any branch or trunk, one from the distal end, one from the middle position and one from the proximal end, material being combined for analysis.

The leaf area of separate samples of leaves from the different branch orders was determined on trees one to eight years old by a blue-printing method involving the weighing of paper leaf prints and relating the weight of leaf print to weight of paper of known area.

The nitrogen, phosphorus, potassium, magnesium, calcium and manganese concentrations were determined in all plant samples. The boron, sulphur, copper, molybdenum, zinc and iron concentrations were determined for all trees, excluding the four-year-old PB 86, LCB 1320 and GT 1 trees.

RESULTS

Tree Weight

The total fresh weight of the trees and the dry weight of roots, trunk, leaves and branches

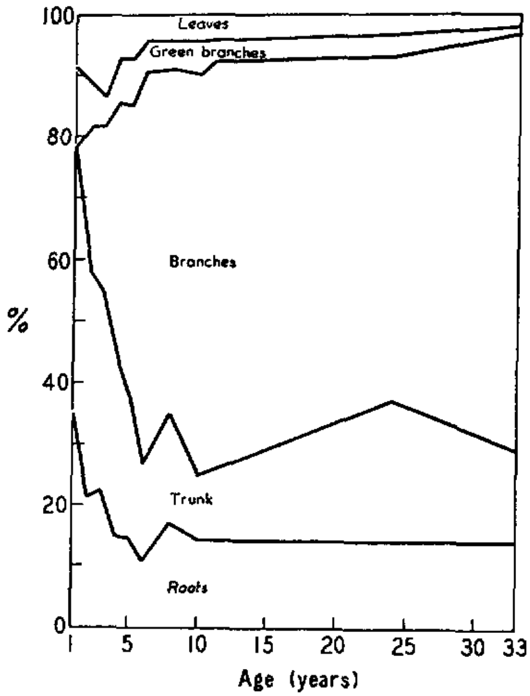

Figure 1. Distribution of dry weight between roots, trunk, branches, green branches and leaves.

(young green branches and older branches showing bark formation being considered separately) are shown in *Table 2*. *Figure 1* shows the dry weight distribution: data of the four-year-old PB 86, GT 1 and LCB 1320 have not been used in constructing *Figure 1*, as the trunk samples were not the entire trunk and there was no separation of the green branches.

The weights of the trees are similar to those reported by OTOUL (1960) and TEMPLETON (1964) for trees of similar ages: Otoul reports shoot weights of 24 kg (3 years), 271 kg (6 years), 619 kg (10 years) and 1197 kg (22 years) and Templeton reports total tree weights of 199 kg (5 years, PR 107) and 239 kg (5½ years, PR 107).

For the trees four to eight years old the roots comprised about 15% of the total tree dry weight; a similar percentage (15.2%) was reported by DYCK (1939). The roots of trees older than eight years were not excavated; in these cases the dry and fresh weights of the entire tree have been estimated on the basis that the determined shoot weight represents 85% of the total tree weight. The term 'shoot weight' is used in this paper to describe all the above-ground parts of the tree.

It is not possible to estimate from the data the variation in growth that is likely to be encountered: clones can differ considerably in their growth rate, and for individual clones variation in environment, particularly of the soil, can markedly affect growth. For instance it can be seen from *Table 2* that the eleven-year-old trees growing on an alluvial sandy soil of low fertility (Sungei Buloh series) were smaller than the ten-year-old trees of the same clone growing on a better soil derived from shale parent material (Malacca series).

It can further be seen from *Table 2*, by comparing the thirty-three-year-old tree that had not been tapped with the thirty-three-year-old tapped trees, that tapping markedly reduces the growth of the tree. However, the untapped thirty-three-year-old tree was growing in a stand of tapped trees of the same age from which the other trees were sampled, and was therefore competing with trees whose growth was retarded on account of tapping; its weight is very probably an overestimate of that of an untapped tree growing in a stand of untapped trees, resulting in an overestimation of the difference between tapped and untapped trees.

Roots. All trees were growing on freely drained soils in which there was no restriction on root growth. The length of the tap root varied from 3 ft in the one-year-old tree to 7½ ft in the eight-year-old tree, while the length of the longest main lateral root was 33 ft.

Not all the finer roots could be collected, and the root weights are thus underestimated; the results show however that the tap root consisted of between 44 and 67% of the total root weight of trees two to eight years old and thus the error is unlikely to be large.

TABLE 2. FRESH WEIGHT AND DRY WEIGHT

(Kg per tree)

Age, years	Clone	Fresh weight	Dry weight							
		Total tree	Roots[c]	Trunk[a]	Branches		Green branches	Leaves	Total shoot	Total tree
1	RRIM 501	6.9	1.01	1.22	nil		0.36	0.25	1.83	2.84
2	RRIM 501	43.3	4.11	6.97	4.49		1.27	2.05	14.78	18.89
3	RRIM 501	78.6	8.92	12.49	10.45		1.78	5.07	29.79	38.71
4	PB 86	56.6[b]	—	4.77[d]		15.98[e]		1.42	22.17	26.08[b]
4	GT 1	106.4[b]	—	8.57[d]		29.44[e]		4.63	42.64	50.16[b]
4	LCB 1320	163.4[b]	—	10.21[d]		44.19[e]		7.40	61.80	72.71[b]
4	RRIM 501	240.8	18.39	33.43	48.58		8.15	8.01	98.17	116.56
5	RRIM 501	306.4	23.35	34.47	74.03		11.92	10.15	130.57	153.92
6	RRIM 501	670.7	37.34	54.25	212.67		16.01	13.56	296.49	333.83
8	RRIM 501	569.1	50.34	50.66	157.52		11.58	12.14	231.90	282.24
10	RRIM 501	1940.8[b]	—	102.16	631.94		52.19	37.10	823.39	968.72[b]
11	Tjir 1	1495.8[b]	—	95.91	543.02		31.09	26.30	696.32	819.22[b]
24	RRIM 501	2073.0[b]	—	248.30	617.39		37.15	28.40	931.24	1095.60[b]
33	Tjir 1	3517.5[b]	—	316.97	1439.35		28.14	16.50	1800.96	2118.83[b]
33[f]	Tjir 1	7666.3[b]	—	916.33	2820.84		92.13	73.61	3902.91	4591.77[b]

[a] Trunk and union. [b] Root weight estimate included (on basis that roots comprise 15% of weight of tree). [c] Where no figures are given the root weight was not determined. [d] Weight of five-foot lengths of trunk (measured from the union); remaining trunk included in branches. [e] All branches weighed together. [f] Tree not tapped.

Trunk and branch bark. The weight of the bark accounted for 9 to 13% of the total trunk weight, with the exception of the thirty-three-year-old tapped tree in which bark accounted for only 5% of the total trunk weight. On the first order branches and in small branches (2 to 5 cm diameter) 9 to 15% of the branch weight was accounted for by the bark.

Leaves and Leaf Area Index

The proportion of leaves declined abruptly from a maximum of 13% of the total tree dry weight in the three-year-old trees to about 7% in the four-year-old trees, and thereafter a gradual decline occurred to about 1% in the thirty-three-year-old trees (*Figure 1*).

The petioles were cut off from the laminae and found to contribute 15 to 19% of the total leaf weight.

The leaf area per gram dry weight of lamina varied from 127 (in the one-year-old trees) to 159 sq. cm (in the six- and eight-year-old trees) with an average value for the five- to eight-year-old trees of 150.3 sq. cm: this latter value has been used to calculate the leaf area of the older trees.

Leaf area data are presented in *Table 3*, and of particular interest is the leaf area index which is the total area of leaves present per unit area of land. The leaf area index was found to increase from 0.14, in the one-year-old trees, to a maximum of 14 in the ten-year-old trees and to decline thereafter to 5.4 in the thirty-three-year-old trees. At the time of closing over of the canopy in the fourth, fifth and sixth year the leaf area index ranged 3.4 to 6.3. Since the sampled trees were selected as being of average vigour it seems likely that these leaf area index values may at times be exceeded in particularly vigorous stands of rubber.

Nutrient Composition

The nutrient concentrations in the trunk, branches, green branches, leaves and roots are shown in *Table 4*. There was no interaction between the levels of nutrients, the age of the tree and site, and only the mean values together with the range encountered are given for each morphological unit; more detailed nutrient concentration data for each age, also for the bark and wood of the trunk and first order branches, and in leaves and petioles separately, are given in a *Supplement to this paper* (SHORROCKS, 1964). The average nutrient percentages for each morphological unit were calculated by dividing the total amount of nutrient in that unit by its dry weight: thus a mean figure for that unit and not a simple average of analytically determined values was obtained. Little variation

TABLE 3. LEAF AREA AND LEAF AREA INDEX

Age, in years	Clone	Leaf area sq. metre/tree	Leaf area sq. metre/hectare	Leaf area index
1	RRIM 501	2.57	1,143	0.14
2	RRIM 501	23.99	10,675	1.07
3	RRIM 501	58.96	26,237	2.62
4	RRIM 501	84.05	34,292	3.43
5	RRIM 501	110.99	41,177	4.12
6	RRIM 501	182.09	63,003	6.30
8	RRIM 501	163.81	52,583	5.26
10	RRIM 501	474.02[a]	140,309	14.03
11	Tjir 1	334.85[a]	99,115	9.91
24	RRIM 501	361.91[a]	89,391	8.94
33	Tjir 1	202.56[a]	54,083	5.41
33[b]	Tjir 1	925.97[a]	—	—

[a] Leaf area calculated from laminae dry weight using factor of 150.3 sq. cm per g laminae.
[b] Tree not tapped growing in stand of tapped trees.

TABLE 4. AVERAGE AND RANGE OF NUTRIENT CONCENTRATIONS IN ROOTS, TRUNK, BRANCHES, GREEN BRANCHES, LEAVES

(Range given in brackets)

Nutrient element	Roots	Trunk	Branches	Green branches	Leaves
% nitrogen	0.62 (0.44—0.93)	0.45 (0.25—0.70)	0.45 (0.29—0.64)	0.93 (0.50—1.21)	2.79 (2.34—3.23)
% phosphorus	0.09 (0.05—0.12)	0.05 (0.03—0.08)	0.05 (0.03—0.09)	0.11 (0.07—0.18)	0.18 (0.15—0.22)
% potassium	0.31 (0.20—0.48)	0.25 (0.10—0.48)	0.27 (0.08—0.46)	0.63 (0.24—0.99)	0.90 (0.69—1.07)
% magnesium	0.15 (0.10—0.18)	0.12 (0.08—0.16)	0.09 (0.03—0.12)	0.12 (0.05—0.20)	0.24 (0.14—0.32)
% calcium	0.31 (0.16—0.49)	0.33 (0.18—0.52)	0.30 (0.18—0.54)	0.82 (0.23—1.47)	0.86 (0.38—1.33)
% sulphur	0.06 (0.05—0.08)	0.06 (0.04—0.09)	0.06 (0.02—0.09)	0.12 (0.04—0.19)	0.22 (0.20—0.26)
p.p.m. manganese	17 (8—43)	25 (8—73)	26 (9—70)	90 (21—397)	211 (45—1034)
p.p.m. iron	233 (120—323)	30 (10—55)	37 (15—101)	71 (22—206)	182 (73—441)
p.p.m. boron	4 (3—6)	4 (2—6)	3 (1—5)	6 (2—9)	29 (20—52)
p.p.m. zinc	15 (13—18)	16 (10—23)	8 (5—11)	12 (6—22)	23 (15—51)
p.p.m. copper	4 (2—5)	3 (1—5)	4 (2—8)	11 (6—14)	11 (9—19)
p.p.m. molybdenum	0.20 (0.13—0.29)	0.20 (0.10—0.38)	0.14 (0.03—0.40)	0.16 (0.05—0.48)	0.17 (0.07—0.38)

was found between the nutrient composition of roots, trunk and branches: the concentrations of the various nutrients in the green branches, however, were greater than those in the branches and trunk, sometimes by as much as two to three times. The leaf nutrient concentrations exceeded those in the trunk and branches by factors ranging from two to ten times, the differences in the case of manganese and boron being particularly wide; in contrast the concentrations of magnesium, copper and zinc in the leaves were only slightly greater than the concentrations found in the branches and trunk. Very high concentrations of iron were found in the roots, possibly due to immobilisation of this element and to surface contamination that could not be removed by washing. Nutrient concentrations in the bark were generally greater than those of the wood, particularly in the case of calcium where the bark concentration exceeded that in the wood by factors ranging from ten to thirty times. The concentrations of manganese and iron in the bark exceeded that in the wood by factors ranging from three to eight times; for other nutrients the differences between bark concentrations and wood concentrations were smaller, and in the case of sulphur no difference was found.

It is interesting to note that relatively little difference was found between the nutrient concentrations of the tapped and untapped thirty-three-year-old trees. In view of the much greater weight of the untapped tree, and thus the greater requirement for nutrients, it would appear that the soil supply of nutrients was not limiting the growth of the tapped tree.

Total Nutrient Content

The nutrient contents of the shoot as determined, together with the calculated total nutrient contents per hectare of standing trees (including an estimate of the root content based on the average root nutrient content for the four-, five-, six- and eight-year-old trees) are given in *Tables 5, 6* and *7*: the numbers of trees per hectare used to calculate the total nutrient content per hectare are those given in *Table 1*; it must be remembered that the thirty-three-year-old tapped tree was growing in a stand of tapped trees of similar age.

The average annual nutrient uptake of the tree from the time of planting can be assessed from the total nutrient content data: for instance the average annual nitrogen, phosphorus, potassium and magnesium uptake of the mature trees, as determined from the individual tree data (five to thirty-three years old) by dividing the total nutrient content by the age, are 293 g nitrogen, 29 g phosphorus, 125 g potassium and 46 g magnesium. In contrast, the annual uptake of calcium and sulphur, nutrients not normally intentionally supplied as individual nutrients to the tree, are 178 g and 32 g respectively: the tree thus absorbs about the same weight of sulphur as of phosphorus and the uptake of calcium exceeds that of either of the other two cations, potassium and magnesium.

The annual uptake of nutrients during the mature phase only has been calculated from the tree data covering the four periods 5 to 24, 5 to 33, 6 to 24 and 6 to 33 years by first subtracting the nutrient content of the younger tree from that of the older tree of each period and then dividing by the difference in age (years). The average annual nutrient uptake during maturity based on these four periods are 187 g nitrogen, 32 g phosphorus, 142 g potassium, 37 g magnesium, 206 g calcium and 22 g sulphur: these values are similar to those based on the entire life of the sampled mature trees for all nutrients except nitrogen, for which the estimate based on the mature phase only is lower, indicating a decline in the rate of nitrogen uptake with time.

The distribution of the individual nutrients in the different parts of the tree followed the pattern expected from the dry weight distribution. For the trees older than five years, *Figure 2* shows that approximately half the nitrogen, phosphorus, potassium and magnesium content of the tree is contained in the branching system, that the trunks and roots contain about equal proportions of these nutrients, and that the green branches and leaves contain only a small proportion of the

TABLE 5. NITROGEN, PHOSPHORUS, POTASSIUM AND MAGNESIUM CONTENT OF STANDING TREES

(Shoot content as determined, g per tree. Total tree content calculated in kg per hectare[b] on basis of stand per hectare shown in *Table 1*)

Age, years	Clone	Nitrogen		Phosphorus		Potassium		Magnesium	
		Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare
1	RRIM 501	17	11.8	2	1.4	12	7.0	3	2.1
2	RRIM 501	136	72.3	12	7.2	74	41.6	25	14.1
3	RRIM 501	282	149.6	26	14.6	107	57.9	35	20.3
4	PB 86	162	72.2*	18	8.6*	136	61.6*	25	12.2*
4	GT 1	399	177.9*	39	18.0*	207	93.9*	46	22.4*
4	LCB 1320	512	228.4*	41	19.2*	307	139.6*	58	28.3*
4	RRIM 501	758	351.1	62	30.0	399	187.6	123	62.8
5	RRIM 501	1126	478.9	97	42.9	360	151.1	176	81.2
6	RRIM 501	1930	728.0	164	63.6	814	311.8	289	118.8
8	RRIM 501	1515	558.0	130	49.4	744	289.8	212	85.0
10	RRIM 501	4572	1529.2*	413	143.1*	1501	510.6*	663	241.6*
11	Tjir 1	2797	935.6*	354	122.7*	802	272.9*	302	110.2*
24	RRIM 501	4682	1306.7*	331	95.8*	2854	810.4*	639	194.0*
33	Tjir 1	5895	1778.6*	884	276.5*	4018	1233.2*	1270	416.8*
33[a]	Tjir 1	13297	4011.8*	3387	1058.9*	14429	4428.3*	2810	922.8*
		* Root estimate included on basis that 11.5% of total nitrogen is contained in roots.		*Root estimate included on basis that 14.6% of total phosphorus is contained in roots.		*Root estimate included on basis that 13.0% of total potassium is contained in roots.		*Root estimate included on basis that 18.7% of total magnesium is contained in roots.	

[a] Tree not tapped. [b] 1 kg per hectare = 0.89 lb per acre.

TABLE 6. CALCIUM, SULPHUR, MANGANESE AND IRON CONTENT OF STANDING TREES

(Shoot content as determined, g per tree. Total tree content calculated in kg per hectare on basis of stand per hectare shown in *Table 1*)

Age, years	Clone	Calcium		Sulphur		Manganese		Iron	
		Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare
1	RRIM 501	9	4.5	2	1.2	0.27	0.14	0.07	0.14
2	RRIM 501	67	34.9	14	7.5	0.30	0.16	0.64	0.50
3	RRIM 501	188	98.8	28	14.3	0.68	0.35	1.03	1.08
4	PB 86	118	54.2*	n.d.	n.d.	0.69	0.30*	n.d.	n.d.
4	GT 1	207	95.5*	n.d.	n.d.	1.22	0.53*	n.d.	n.d.
4	LCB 1320	250	115.2*	n.d.	n.d.	1.54	0.67*	n.d.	n.d.
4	RRIM 501	364	168.7	106	48.1	1.23	0.56	4.55	4.28
5	RRIM 501	388	175.0	132	54.4	3.43	1.36	7.51	5.39
6	RRIM 501	981	370.3	206	77.4	8.14	3.03	30.15	14.40
8	RRIM 501	1047	414.7	173	64.0	5.10	1.92	15.56	8.13
10	RRIM 501	2190	756.5*	422	139.3*	33.31	10.94*	17.32	8.96
11	Tjir 1	1542	532.8*	331	109.3*	15.28	5.02*	10.42	5.39
24	RRIM 501	3088	890.1*	515	141.7*	46.66	12.79*	24.55	10.60
33	Tjir 1	6801	2118.9*	803	238.9*	52.40	15.53*	29.51	13.78*
33[a]	Tjir 1	10756	3351.1*	2555	760.6*	393.96	116.74*	75.87	35.41*
		*Root estimate included on basis that 14.3% of total calcium is contained in roots.		*Root estimate included on basis that 10.3% of total sulphur is contained in roots.		*Root estimate included on basis that 9.9% of total manganese is contained in roots.		*Root estimate included on basis that 42.8% of total iron is contained in roots.	

[a] Tree not tapped   n.d. Not determined.

TABLE 7. BORON, ZINC, COPPER AND MOLYBDENUM CONTENT OF STANDING TREES

(Shoot content as determined, g or mg per tree. Total tree content calculated in kg or g per hectare on basis of stand per hectare shown in *Table 1*)

Age, years	Clone	Boron		Zinc		Copper		Molybdenum	
		Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare	Shoot, g/tree	Total tree, kg/hectare	Shoot, mg/tree	Total tree, g/hectare
1	RRIM 501	0.01	0.01	0.03	0.02	0.01	0.01	0.2	0.16
2	RRIM 501	0.16	0.08	0.18	0.11	0.08	0.04	2.1	1.24
3	RRIM 501	0.29	0.14	0.32	0.20	0.14	0.80	3.4	2.49
4	RRIM 501	0.65	0.30	1.13	0.57	0.55	0.25	27.0	12.90
5	RRIM 501	1.12	0.46	1.32	0.64	1.12	0.44	47.3	20.04
6	RRIM 501	1.32	0.51	4.11	1.58	2.34	0.84	80.3	29.62
8	RRIM 501	1.10	0.43	2.85	1.13	1.00	0.36	42.8	16.14
10	RRIM 501	2.69	0.91*	67.25	2.62*	3.48	1.12*	116.4	40.07*
11	Tjir 1	2.03	0.69*	6.26	2.25*	1.99	0.64*	40.7	13.99*
24	RRIM 501	1.81	0.51*	11.91	3.58*	3.07	0.82*	58.6	16.84*
33	Tjir 1	5.45	1.66*	15.16	5.08*	3.74	1.09*	132.2	41.04*
33[a]	Tjir 1	16.15	4.91*	44.91	14.61*	14.30	4.15*	252.0	78.25*
		*Root estimate included on basis that 12.2% of total boron is contained in roots.		*Root estimate included on basis that 17.9% of total zinc is contained in the roots.		*Root estimate included on basis that 8.1% of total copper is contained in the roots.		*Root estimate included on basis that 14% of total molybdenum is contained in the roots.	

[a] Tree not tapped.

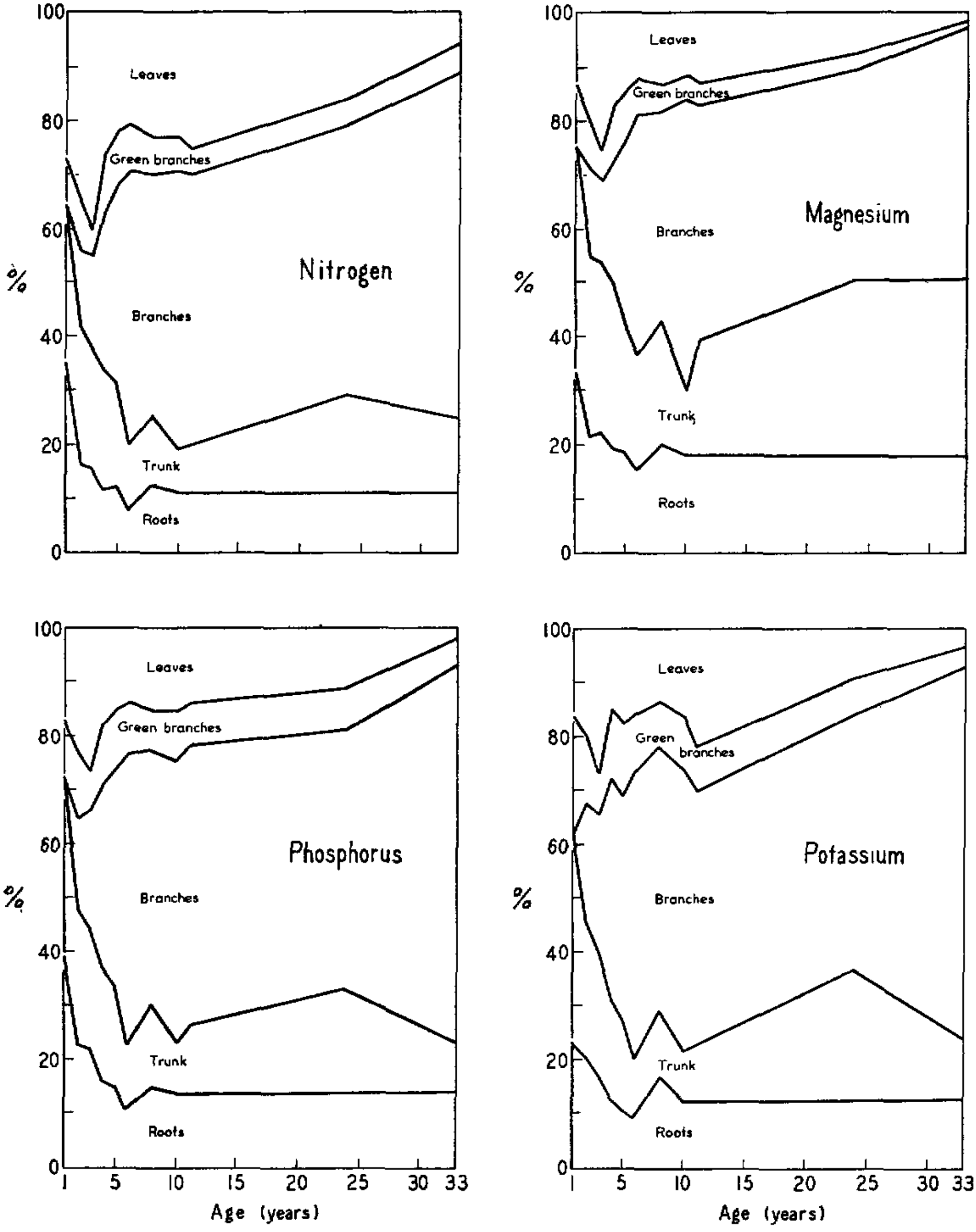

Figure 2. Distribution of nitrogen, phosphorus, magnesium and potassium between roots, trunk, branches, green branches and leaves.

TABLE 8. DRY WEIGHT OF STANDING TREES, CUMULATIVE TOTAL DRY WEIGHT OF THINNED TREES, OF ANNUAL LEAF AND FRUIT FALL (KG PER HECTARE)

Age, years	Clone	Standing trees	Thinned trees	Leaf fall	Fruit	Total
1	RRIM 501	1,261	0	0	0	1,261
2	RRIM 501	8,405	0	109	0	8,514
3	RRIM 501	17,225	0	1,021	0	18,246
4	RRIM 501	47,555	1,443	3,277	0	52,275
5	RRIM 501	57,103	5,735	6,541	0	69,379
6	RRIM 501	115,507	9,585	10,307	160	135,559
8	RRIM 501	90,600	17,935	19,529	480	128,544
10	RRIM 501	286,741	24,985	30,818	800	343,344
11	Tjir 1	242,490	24,985	41,799	960	310,234
24	RRIM 501	270,614	65,116	129,612	3,040	468,382
33	Tjir 1	565,728	48,736	184,686	4,480	803,630

total nutrient content, a proportion which declines with age to 10% and less.

DISCUSSION

Estimation of Total Dry Matter Production

It is possible from the results to estimate the net production of dry matter (i.e. gross assimilation minus respiratory losses) by a stand of rubber trees. The total dry weight of the standing trees (kg per ha), shown in *Table 8* does not represent the total net production of dry matter since the weight of trees removed on thinning, and the weights of leaf, branch and seed falling each year are not included. The weights of thinned trees for any period have been estimated by multiplying the decrease in number of trees per hectare in the period between two consecutive tree ages (which can be taken as equivalent to normal thinning rates) by the weight per tree at the beginning of the period, e.g. number of trees thinned between the third and fourth year was 37 per ha and the weight of the three-year-old tree was 39 kg, the total weight of thinned trees thus being estimated at 1,443 kg per ha. The weights of trees thinned between later periods have been similarly calculated and added to the weights thinned in all the previous periods to obtain the cumulative total weight of trees removed by thinning for each age: these estimates are given in *Table 8*. It is assumed in this calculation that the thinned trees were of average size; however as thinned trees are usually the most poorly grown trees the method of calculation may result in an overestimation of total dry matter production. The amounts of dry matter lost in branch fall each year are however not known for the sampled trees, and their non-inclusion in the estimate will tend to minimise any overestimation resulting from the inclusion of thinned tree weight. The weights of branches which fall can be very large: in one investigation with eleven- and thirty-one-year-old trees respectively branch fall amounted to 12,115 and 7,774 kg per ha per annum (WONG, 1964).

The cumulative weight of leaf fall per hectare has been calculated assuming that each year the tree drops all its leaves. This estimate of the annual leaf production is likely to be low owing to the leaf formation and defoliation which occurs during the year and which is not accounted for in the determined weight of foliage. Leaf litter (laminae and petioles) collected under four- to five-year-old trees (clone RRIM 603) was found by WONG (1964) to total 3,610 kg per ha in one year. This weight corresponds well with that of leaves found on the three-year-old trees (clone RRIM 501): these particular trees were not completely devoid of leaves at any time in the year, and it may be tentatively concluded that a four-year-old tree drops leaves throughout the year amounting approximately to the total weight found on the tree at any time during the year.

No measurements of seed and capsule fall were made in any of the sampled areas. It may be roughly estimated that about 8,300 fully developed fruit each containing three seeds are produced per hectare every year from the sixth year onwards (ROSS, 1964), although considerable variation is known to occur.

Average dry weights of 1.8 g per seed and 14.0 g per capsule were determined from a sample of nearly ripe fruit (clone RRIM 501), giving a total dry weight per fruit of 19.4 g. On the basis of a production of 8,300 mature fruit per hectare per annum the weight of fruit fall amounts to approximately 160 kg per ha per annum and this estimate has been used for the data quoted in *Table 8* commencing in the sixth year. The weight of inflorescences and immature capsules which fall prematurely may equal that of the mature fruit, but this has not been allowed for in the above estimate which is accordingly an underestimate of dry matter production.

On the above calculations, during the first five years of growth, the rate of dry matter production increased from about 1,000 to 14,000 kg per ha per annum, and during the period when the canopy forms a complete ground cover the rate of dry matter production (average of the trees six to thirty-three years old) was approximately 24,000 kg per ha per annum. This rate of dry matter production is roughly of the same order as that reported by NYE (1961) for secondary forest in Ghana, (24,400 kg per ha per annum), for maximum growth of pine forest in England (22,000 kg per ha per annum, OVINGTON, 1957) and evergreen forests in Japan (21,600) and Thailand (25,300) (OGAWA *et al.*, 1961), and slightly in excess of that for oil palm in Ghana (19,500 kg per ha per annum, REES AND TINKER, 1963).

Leaf Area Index

Values for the leaf area index of the ten-, eleven- and twenty-four-year-old trees, were greater than those reported for agricultural crops and pasture (WATSON, 1958; DONALD AND BLACK, 1958) and also for trees (RUTTER, 1957; OVINGTON AND MADGWICK, 1959). The index values were obtained from only a limited number of trees and it is considered that values in excess of those reported can be expected in well grown stands of rubber, as none of the trees sampled had particularly dense canopies. Further studies designed to determine the optimal leaf area index for *Hevea* would seem to be required, for it seems reasonable to expect with leaf area index values greater than ten, that there is sufficient mutual shading to result in a reduction in the light intensity below the compensation point (where respiratory losses exceed assimilatory gains) for leaves low down in the canopy.

The premature senescence of leaves low down in the shade of the canopy, which is frequently observed a few months after refoliation on trees with dense canopies, will reduce the leaf area index. Owing to the relatively large proportion of branch material it is likely that branch weight will also have to be considered in the same context: the lower branches, growing in light intensities below the compensation point, like the leaves, contribute largely to respiratory losses and probably very little to the assimilatory gains. The dying-back or 'self pruning' of these branches may be of benefit by reducing the amount of unproductive material on the tree in a manner similar to the premature leaf fall on trees with large amounts of leaf.

Nutrient Uptake and Fertiliser Requirement

A large uptake of calcium has been demonstrated, which in terms of weight of the element is greater than that of all other nutrients except nitrogen: some 30—50% of this calcium is deposited in the trunk and branch bark, and it is possible that not all of that taken up is truly essential to the growth of the tree. It would appear that the calcium nutrition of the tree, which has not been studied as intensively as that of nitrogen, phosphorus, potassium and magnesium should be given greater attention, not only because of the large uptake of this nutrient, but also on account of soil fertility considerations (SHORROCKS, 1961; BOLTON, 1963; and MIDDLETON AND CHIN, 1964).

As expected the micro-nutrient content of the tree is very small; the manganese content varied up to approximately 50 g, that of boron up to approximately 6 g and that of molybdenum up to 150 mg per tree. These data make more understandable such features as the correction of manganese deficiency in mature trees by the application of only a few ounces of manganese sulphate per tree (SHORROCKS AND WATSON, 1961), the ease with which boron toxicity may be induced by applying only one ounce of borax (RUBBER RESEARCH INSTITUTE OF MALAYA, 1964a), and the marked effect of a few grams of sodium molybdate applied to the soil in improving the molybdenum status of leaves of mature trees (SHORROCKS, 1961).

The relatively high concentration of manganese found in the bark affords some explanation of the high concentration of manganese found in bark scrap rubber (SHORROCKS AND WATSON, 1961): it appears likely that manganese diffuses out of the bark into the bark scrap rubber which remains in intimate contact with the bark, during the period between tappings.

A comparison of the data on total nutrient uptake by rubber given in this paper, with the nutrient content of a typical soil, has shown that a severe strain on the soil nutrient reserves is likely to develop during the life of a plantation (WATSON, 1964); generous and scientifically formulated fertiliser dressings will obviously be required in order to maintain optimum growth. The above data indicate that the average annual uptake of nitrogen, phosphorus, potassium and magnesium during maturity (excluding that withdrawn from the tree in latex, a feature which will be discussed in a later paper) is of the order of 187 g nitrogen, 32 g phosphorus, 142 g potassium and 37 g magnesium; a routine 'maintenance' fertiliser dressing that is commonly applied to mature rubber is 2 lb per tree R.R.I.M. Mixture Magnesium C_2 (RUBBER RESEARCH INSTITUTE OF MALAYA, 1963) which supplies approximately 63%, 106%, 19% and 30% of the annual requirement for nitrogen, phosphorus, potassium and magnesium respectively.

In view of the frequent occurrence of magnesium and potassium deficiencies on mature rubber it would appear that Mixture Magnesium C_2 (2 lb per tree) is not suitable for general application to rubber growing on soils that are low in potassium and magnesium. If efficient use is to be made of fertilisers it is evident that more discrimination is required, by relating the fertiliser used to the nutrient supplying capacity of the soil and the nutrient status of the trees growing on that soil (RUBBER RESEARCH INSTITUTE OF MALAYA, 1964b).

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REFERENCES

BEAUFILS, E. R. AND NGUYEN, H. C. (1957) Diagnostic physiologique—apport d'éléments compensateurs. *Rapp. I.R.C.V. 1956*, 80.

BOLLE-JONES, E. W. (1957) Foliar diagnosis of mineral status of *Hevea* in relation to bark analysis. *J. Rubb. Res. Inst. Malaya* **15**, 109.

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.

CONSTABLE, D. H. (1955) Girth and growth measurements as an aid to manurial diagnosis in tropical horticulture. *Rep. XIVth int. Hort. Congr. 1955*, **2**, 1346.

DONALD, C. M. AND BLACK, J. N. (1958) The significance of leaf area in pasture growth. *Herb. Abstr.* **28**, 1.

DYCK, A. W. J. (1939) The amounts and distribution of some of the nutrient elements in the rubber tree. *J. Rubb. Res. Inst. Malaya* **9**, 6.

MIDDLETON, K. R. AND CHIN, T. T. (1964) A comparison of rock phosphate with superphosphate and of ammonium sulphate with sodium nitrate, as sources of phosphorus and nitrogen for rubber seedlings I. The effect upon growth and soil pH. *J. Rubb. Res. Inst. Malaya* **18,** 109.

NYE, P. H. (1961) Organic matter and nutrient cycles under moist tropical forest. *Plant & Soil* **13,** 333.

OGAWA, HUSATO, YODA, K. AND KIRA, T. (1961) A preliminary study of the vegetation of Thailand. *Nat. & Life in S.E. Asia.* **1,** 22.

OTOUL, E. (1960) Le système radiculaire de l'*Hévéa* dans les conditions écologiques de Yangambi. *Sér. Techn. Inst. Nat. L'Etude Agron. Congo* No. 62.

OVINGTON, J. D. (1957) Dry-matter production by *Pinus sylvestris L. Ann. Bot., Lond.* **21,** 287.

OVINGTON, J. D. AND MADGWICK, H. A. I. (1959) The growth and composition of natural stands of birch I. Dry-matter production. *Plant & Soil* **10,** 271.

OWEN, G. (1951) A provisional classification of Malayan soils. *J. Rubb. Res. Inst. Malaya.* **13,** Comm. 274, 20.

REES, A. R., AND TINKER, P. B. H. (1963) Dry-matter production and nutrient content of plantation oil palms in Nigeria. *Plant & Soil* **19,** 19.

ROSS, J. M. (1964) Private communication. R.R.I.M.

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

RUBBER RESEARCH INSTITUTE OF MALAYA (1964a) *Rep. Rubb. Res. Inst. Malaya* 1963, 16.

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

RUTTER, A. J. (1957) Studies in the growth of young plants of *Pinus sylvestris* L. I. The annual cycle of assimilation and growth. *Ann. Bot., Lond.* **21,** 399.

SHORROCKS, V. M. (1961) Some effects of fertiliser applications on the nutrient composition of leaves and latex of *Hevea brasiliensis. Proc. Nat. Rubb. Res. Conf. Kuala Lumpur, 1960,* 118.

SHORROCKS, V. M. (1964) A supplement to the paper : Mineral nutrition, growth and nutrient cycle of *Hevea brasiliensis* I. Growth and nutrient content. *Research Archives of the R.R.I.M.* Document No. 37.

SHORROCKS, V. M. AND WATSON, G. A. (1961) Manganese deficiency in *Hevea:* The effect of soil application of manganese sulphate on the manganese status of the tree. *J. Rubb. Res. Inst. Malaya* **17,** 19.

TEMPLETON, J. K. (1964) Private communication. R.R.I.M.

WATSON, D. J. (1958) The dependence of net assimilation rate on leaf-area index. *Ann. Bot., Lond.* **22,** 37.

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

WONG, P.W. (1964) Private communication. R.R.I.M.