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Feeder Root Development of Hevea brasiliensis in Relation to Clones and Environment

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The development of the feeder roots of Hevea brasiliensis *was studied in relation to clones, soil series, seasons and cover management. The results showed significant differences in feeder root proliferation between clones; vigorous growing clones had significantly more feeder roots than slow growing clones at all soil depths considered.*

Effect of soil on feeder root development was also found to be significant. RRIM 623 clone growing on very sandy soils like Sungei Buloh and Holyrood series produced two and half times more feeder roots than on clayey soils like Selangor and Munchong series.

In the evaluation of the vertical distribution of feeder roots, it was found that in most soils the greatest root proliferation was in the topsoil and the proliferation decreased rapidly with depth. Variability in feeder root development on different soil series is discussed in relation to the physical properties of the soils.

The results also showed significant changes in feeder root development at certain seasons. Maximum root development occurred in February/March, corresponding to the period of active refoliation and peak uptake of moisture and nutrients by the tree. Minimum root development was around August to December when leaf senescence sets in. Cover management also exerted a large influence on root development. In young rubber trees, it was found that leguminous creeping cover enhanced better rooting than grass or Mikania.

The morphology of *Hevea* root systems at different ages of the tree and under different ecological conditions was initially studied by RUBBER RESEARCH INSTITUTE OF MALAYA (1958), OTOUL (1960) and SOONG *et al.* (1971). These qualitative studies showed that the rubber tree possesses an extensive root system that is adapted for exploiting large volume of soil. It has both a well-developed tap root and lateral roots and also large numbers of fine rootlets that help to increase the tree's absorptive capacity for moisture and nutrients. Studies made on these fine rootlets (or 'feeder roots' as they are often termed) show that they are the main active absorbing zones of the root system (GUHA, 1968). This indicates that their development and distribution in the soil have a great influence on the growth and nutrition of the rubber tree.

So far there is little information on the feeder root system of rubber trees, especially with respect to its development and distribution in relation to environmental changes and soil management practices. The aim of this study was to investigate the effects of some of these environmental factors and management practices on development of feeder root in rubber trees to enable a better understanding of some growth and nutritional problems encountered in rubber cultivation. As the various clones of *Hevea* are known to have

COMMUNICATION 601

highly variable performances in the field, the rooting habits of a few clones were also investigated.

EXPERIMENTAL

Materials Used

Four clones, namely RRIM 623, RRIM 605, RRIM 519 and RRIM 513 were selected for studying clonal effect on feeder root development. The trees were all established in 1959 in the same field on a jungle clearing on Rengam series soil at the RRIM Experiment Station, Sungei Buloh. These clones were all budded on Tjir 1 root-stock, and from establishment, were maintained uniformly.

For studying effects of soil on feeder root development, seven soil series representing some of the common soils under rubber were selected. They were the Rengam, Sungei Buloh, Selangor, Munchong, Holyrood, Durian and Malacca series soils. These soils vary greatly in geological origin, and also in physical and chemical properties. Detailed descriptions of the profile of these soils used for this study have been reported by SOONG (1971) and classified in accordance with the 7th Approximation by CHAN (1975).

Seasonal effect on feeder root development was studied by detailed and repeated samplings of selected trees at different times of the year. The study was conducted on Rengam and Sungei Buloh series soils located respectively in *Field 65A* and *Field 17* at the RRIM Experiment Station, Sungei Buloh.

Various methods of examining root systems of crops have been described by SHURMAN AND GOEDEWAAGTEN (1965). In the current study, the feeder root development of rubber trees was investigated by taking small soil samples with an auger. The advantage of this method over the excavation method is that it provides a good average picture of the quantity of roots at various soil depths; also, a large number of samples can be taken without difficulty. The selection of trees and the sampling of roots have been reported in detail by SOONG (1971) and hence only the salient features are mentioned here.

The auger used was a modification of the one developed by GOEDEWAAGEN (1948). It consisted of a cylindrical pipe having an internal diameter of 10 cm, welded to a 40 cm hollow shaft. A long handle was fixed to the top of the shaft to enable the auger to be pressed into the soil and pulled out together with the soil core. The shaft contained a rod to which a round disc was welded at the bottom. The rod and the disc were used for forcing the soil specimen out of the pipe. The bottom of the pipe was serrated for cutting the roots neatly away from the soil core.

Observations made on rubber feeder roots showed that they were unsuberised and pale yellowish in colour, with a diameter of 1.06 ± 0.21 mm and so distinct in characteristics that they could be distinguished from other types of roots without much difficulty.

Roots were separated from soil by hand sorting, then washed clean and dried at 80°C for 48 h before weighing. During the sorting of roots, living roots were distinguished and separated from dead roots. Dead roots were far less elastic and darker in colour than living roots. Rubber roots were separated from grass roots with which they were usually associated.

Each tree was taken as a unit of sampling. The area surrounding the selected tree was demarcated into a rectangle with the extreme ends of the rectangle reaching a point midway from the adjoining trees on the same or adjacent rows *(Figure 1)*. Sampling was restricted to the zones of maximum root activity (SOONG, *et al.*, 1971) which is 1 m to 3 m away from the base of the tree. In each sampling unit, ten well distributed sampling points were chosen, with five points being sampled on either side of the tree. Soil cores were collected from depths of 0 – 7.5, 7.5 – 15, 15 – 30 and 30 – 45 cm at each sampling point.

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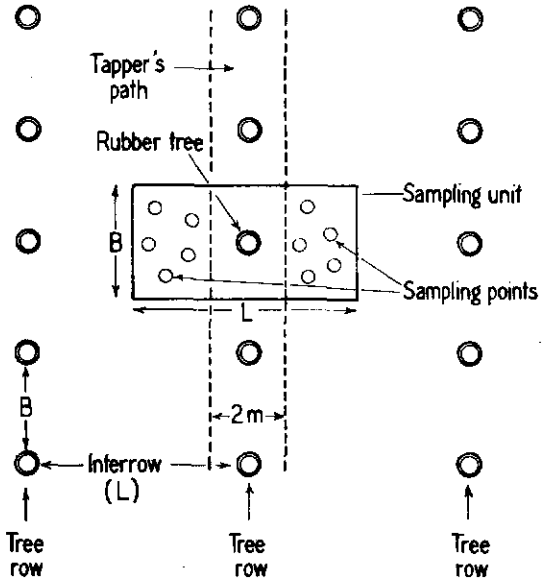

Figure 1. Method of sampling rubber roots.

Preliminary studies made on eight RRIM 623 trees showed that there were significant tree-to-tree variations in the density of feeder roots (expressed in milligrams of dry root per 1000 cc of soil) at each soil depth. The coefficient of variation of the mean root density varied from depth to depth, but the smallest variation was found in the 0—7.5 cm soil depth *(Table 1)*. The observed means, based on eight trees and ten sampling points per tree gave an estimation of the tree means with coefficient of variation of ± 8% to ±16%. As this had the required accuracy for estimating mass of feeder roots all future sampling was on the basis of eight trees per site. The trees selected were similar in age (nine to ten years) uniform in size and vigour and with an average girth of about 65 cm at a height of 150 cm from the union. The trees were established at a density of 450 trees per hectare and the planting was on a rectangular system (3 × 6 m).

TABLE 1. FEEDER ROOT DENSITIES AT DIFFERENT SOIL DEPTHS FOR EIGHT RRIM 623 TREES DETERMINED BY AUGER METHOD

Soil depth (cm)	Mean root density ± S.E. (mg/100 cc of soil)	C.V. (%)
0 - 7.5	374.3 ± 30.3	8.1
7.5 - 15	157.9 ± 25.4	16.2
15 - 30	64.2 ± 9.5	14.8
30 - 45	38.1 ± 4.6	12.1

Analysis

In studying effects of soil on feeder root development, samples were collected from a soil profile pit, dug in each sampling area and analysed for the following: mechanical composition by Pipette Method, organic carbon content by Walkley and Black's Rapid Titration Method, bulk density by the soil core sampler of LUTZ (1947) and discrete ped density by the rubber-coating method described by ABROL AND PALTA (1968). Total porosity was calculated by the relationship:

$$\text{Total porosity (\%)} = (2.65 - \text{Bulk density}) \times \frac{100}{2.65}$$

where the value of 2.65 is taken to be the average specific gravity of the soil.

RESULTS AND DISCUSSION

Clonal Effects on Feeder Root Development of Hevea

The density of feeder roots and their percentage distribution at each soil depth on Rengam series soil for RRIM 605, RRIM 623, RRIM 519 and RRIM 513 are given in *Table 2*. There were significant tree-to-tree variations within each clone, but clonal differences were established at each of the depths. RRIM 605 sustained the greatest feeder root proliferation at all soil depths, and RRIM 513 the lowest. The amount of feeder roots of RRIM

TABLE 2. FEEDER ROOT DENSITIES AND PERCENTAGE DISTRIBUTIONS AT VARIOUS SOIL DEPTHS FOR FOUR CLONES ON RENGAM SERIES SOIL

Clone \ Soil depth (cm)	Mean root density (mg/1000 cc of soil)				Percentage distribution			
	0 - 7.5	7.5 - 15	15 - 30	30 - 45	0 - 7.5	7.5 - 15	15 - 30	30 - 45
RRIM 605	445.0	190.7	91.8	49.4	48.5	20.8	19.7	11.1
RRIM 623	374.3	158.9	63.6	38.8	51.8	20.7	16.9	10.6
RRIM 519	374.3	130.7	53.0	38.8	53.8	19.2	16.0	11.1
RRIM 513	268.4	84.8	42.4	28.3	53.7	17.4	17.2	11.7
S.E. (±)	31.4	16.2	7.8	4.6	4.40	2.56	2.25	1.90
L.S.D. ($P < 0.05$)	91.8	45.9	21.2	14.1	12.7	7.4	6.5	5.5

623 and RRIM 519 were intermediate between the four clones. All four clones showed almost similar patterns in the vertical distribution of feeder roots with the highest percentage of roots being in the surface soil layer (0—7.5 cm). The amount of feeder roots in the surface soil varied from 48.5% of the total feeder roots in RRIM 605 to 53.8% in RRIM 519. Only about 12% of the total root weight was found in the lowest soil layer examined (30—45 cm). For any given soil depth, there is no significant difference in the percentage distribution of feeder roots between the four clones.

The results clearly show that there were significant differences in feeder root development between various clones of *Hevea brasiliensis,* although the influence of factors like climate, planting distance, standard of management, manuring and soil type had been kept to a minimum. Vigorous clones like RRIM 605 and RRIM 623 (PAARDE—COOPER, 1965) had more feeder roots than a less vigorous clone like RRIM 513. It appears, therefore, that the better growth of clones, over others, on a wider range of soils may be due to a larger amount of feeder roots available for absorption of moisture and nutrients.

This, to some extent, has been confirmed in various commercial areas where a less vigorous clone like PB 86 has grown poorly and has shown symptoms of nutrient deficiency in areas where more vigorous clone like Tjir 1 have been healthy and strong (RUBBER RESEARCH INSTITUTE OF MALAYA, 1956). Thus, it is likely that if a clone has the ability to produce a vigorous root system it would be suited for planting over a wide range of soil and climatic conditions. Studies made on forest trees (HOFFMANN, 1920) show that pine trees are better adapted to poor soil conditions than silver fir and spruce because they possess twenty-four times as many root branches as the other temperate forest trees and eight times the absorbing surface. Therefore, further investigations on the root systems of a larger selection of *Hevea* clones are needed for better understanding of the phenomenon of soil/clone interactions and the adaptibility of certain clones to a wide range of soil conditions.

Soil Effects on Feeder Root Development of Hevea

Feeder root development in different soils. As clonal effects on feeder roots have been

shown to be significant; the study of feeder root development under various soil conditions was restricted to one clone.

Since RRIM 623 was grown on a wide variety of soil series, at the time of initiation of the study, it was selected for this investigation. The trees were nine to ten years old and had been in tapping for about four to five years. To reduce seasonal effect as far as possible all the sampling was completed within a period of three months, from May to July.

The mechanical compositions, physical properties and organic carbon contents of the soils used in this investigation are shown in *Table 3*. There was considerable variation in all these quantities.

The mean root densities, at various soil depths, for the three sites of Rengam series soil and six other soil series are shown in *Table 4*. There were significant differences in root densities between the various soils at all the four soil depths considered. In the surface (0−7.5 cm) soil layer, there was marked difference in feeder root density between the various soils, with Sungei Buloh and Holyrood series sustaining the greatest proliferation and Selangor and Munchong series the least. Rengam, Durian and Malacca series form the middle group with root density values ranging from 374.3 mg to 794.6 mg per 1000 cc of soil.

Significantly, more roots were also obtained in Sungei Buloh and Holyrood series at the lower depths. Of the other soils, Munchong series had higher root densities than Rengam, Durian and Malacca series, particularly in the 15−30 cm and 30−45 cm soil depths. In the subsoil (30−40 cm) Malacca series and one site of Rengam series had very low root density.

Differences in the development of feeder roots were also shown to be significant within soil series. The Rengam series soil at *Site 3* had the highest root density at all the four soil depths compared to those at *Sites 1* and *2*. The difference in root density between *Sites 1* and *3* was as much as 60% to 70%, depending on the soil depth. Such variability in root development within the same soil series suggests that the yield and growth of rubber on the same soil series could also vary considerably, depending on the amount of variation in physical and chemical properties of the soils at the various sites.

From the results, two broad patterns of vertical root distribution could be distinguished. In those soils where the subsoil is compact and soil structure coarse (*e.g.* Durian and Malacca series) root penetration to lower depths was poor. Durian and Malacca series soils have more than 50% of the total root weights in the top 7.5 cm of soil and this decreased rapidly with depth until the amount was only about 10% in the lowest soil layer. Therefore, the bulk of nutrient and moisture uptake is likely to occur in the top 15 cm in these two types of soil. Similar trends in the vertical distribution of roots was also found in excessively drained and sandy soils of Sungei Buloh and Holyrood series. However, in those soils which had little profile differentiation and did not possess a compact layer or laterite band (*e.g.* Selangor and Munchong series) root distribution over depth was rather uniform. The surface soil layer contained only about 28% of the total root weight and the decline with depth was more gradual, with more than 20% of root by weight being at the lowest soil layer. Such uniform vertical distribution in Selangor and Munchong series indicates that their subsoils were more uniformly exploited for nutrients and moisture.

The successful growth of roots and their functioning as absorbing surfaces depend on many factors in the soil environment, especially those affecting the mechanical resistance to root extension. Physical factors, like availability of moisture, soil aeration, soil texture and soil structure, have important influence on root growth and development. WEAVER *et al.* (1922) have shown that soil characteristics influence rooting habits of

TABLE 3. PHYSICAL AND CHEMICAL PROPERTIES OF SOILS ON WHICH ROOT STUDY WAS CONDUCTED

Soil series	Location	Depth (cm)	Mechanical composition				Bulk density (g/cc)	Ped density (g/cc)	Total porosity (%)	pH	Organic carbon (%)
			Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)					
Rengam	R R I E S (Site 1)	0-5	34.4	9.2	11.1	39.6	1.06	1.42	60.0	5.0	1.76
		5-25	33.3	7.9	7.2	49.0	1.10	1.53	88.5	4.8	0.85
		25-84	34.9	6.0	2.0	55.1	1.13	1.47	57.4	4.8	0.47
		84-117	30.4	5.2	2.4	60.8	1.10	1.46	58.5	4.7	0.22
		117-152	31.0	8.5	10.1	48.4	n.d.	n.d.	n.d.	4.8	0.13
Rengam	Muar Itam Estate (Site 2)	0-5	36.4	27.6	5.0	29.7	1.29	1.65	51.3	4.6	1.02
		5-36	39.6	19.5	6.2	30.1	1.25	1.60	52.8	4.7	0.75
		36-104	36.7	15.6	4.8	38.9	1.28	1.90	51.7	4.7	0.31
		104-132	28.5	9.8	5.4	50.3	n.d.	n.d.	n.d.	4.8	0.22
Rengam	Repah Est. (Site 3)	0-10	44.1	18.4	5.0	22.3	1.20	1.77	54.7	5.0	0.72
		10-41	51.7	17.0	3.5	27.3	1.16	1.79	56.2	4.9	0.36
		41-74	34.8	12.6	2.9	49.0	1.19	1.81	55.1	5.0	0.30
		74-109	31.5	10.9	4.1	48.4	1.35	1.73	49.1	5.2	0.25
		109-152	30.6	9.8	4.7	48.8	n.d.	n.d.	n.d.	5.1	0.19
Sungei Buloh	R R I E S	0-5	52.1	32.2	3.4	8.4	1.23	n.d.	53.6	5.7	1.40
		5-18	51.6	31.9	5.2	8.0	1.20	n.d.	54.7	5.6	0.78
		18-30	49.0	33.9	5.4	8.6	1.23	n.d.	53.6	5.6	0.70
		30-43	55.0	30.0	5.0	7.6	1.31	n.d.	50.6	5.2	0.69
		43-94	48.9	34.9	3.0	10.0	1.39	n.d.	47.6	5.0	0.18
		94-152	56.5	35.8	4.7	4.7	n.d.	n.d.	n.d.	5.2	0.04

n.d. = not determined

TABLE 3. PHYSICAL AND CHEMICAL PROPERTIES OF SOILS ON WHICH ROOT STUDY WAS CONDUCTED (Contd)

Soil series	Location	Depth (cm)	Mechanical composition Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Bulk density (g/cc)	Ped density (g/cc)	Total porosity (%)	pH	Organic carbon (%)
Selangor	Sg. Buloh Estate	0-15	0.9	5.7	32.2	26.6	0.62	0.92	n.d.	3.8	18.20
		15-41	0.4	15.6	36.1	45.7	0.79	1.32	n.d.	3.9	2.16
		41-91	1.5	13.2	34.9	44.8	0.67	1.22	n.d.	3.6	2.33
Munchong	Lanchang Estate	0.5	30.0	21.2	7.3	33.8	1.02	1.40	61.5	4.0	2.59
		5-36	28.1	21.5	4.2	42.7	1.16	1.64	56.2	4.4	0.89
		36-152	24.2	17.3	2.6	52.3	1.19	1.85	55.1	4.4	0.56
Holyrood	Kota Bahroe Estate	0-8	48.2	34.4	2.5	12.9	1.32	1.62	50.2	5.6	0.81
		8-36	41.7	29.4	4.1	23.0	1.41	1.66	46.8	5.0	0.27
		36-152	40.3	27.7	3.2	25.8	1.37	1.72	48.3	5.2	0.14
Durian	Tampin Linggi	0-8	5.6	17.1	29.0	44.0	0.94	1.39	64.5	4.5	1.64
		8-30	4.5	14.1	32.5	47.9	1.08	1.57	59.3	4.6	0.56
		30-53	4.9	10.3	32.0	51.1	1.18	1.53	55.5	4.6	0.41
		53-61	24.3	12.2	29.4	33.3	n.d.	n.d.	n.d.	4.6	0.26
		61-79	6.3	14.2	43.7	37.3	n.d.	n.d.	n.d.	4.6	0.20
		79-152	0.9	15.3	61.3	19.5	n.d.	n.d.	n.d.	4.6	0.07
Malacca	Bradwall Estate	0-5	26.7	16.1	11.2	36.4	1.03	1.61	61.1	4.5	2.42
		5-23	17.1	16.7	11.1	49.8	1.03	1.37	61.1	4.5	1.07
		23-48	18.8	13.0	10.6	51.5	1.05	1.57	60.4	4.6	0.77
		48-114	29.3	10.9	7.1	47.8	n.d.	1.75	n.d.	4.7	0.40
		114-152	23.8	13.2	13.1	44.5	n.d.	n.d.	n.d.	4.6	0.20

n.d. = not determined

TABLE 4. FEEDER ROOT DENSITIES AND PERCENTAGE DISTRIBUTION AT VARIOUS SOIL DEPTHS FOR NINE SOILS

Soil series \ Soil depth (cm)	Mean root density (mg/1000 cc of soil)				Percentage distribution			
	0-7.5	7.5-15	15-30	30-45	0-7.5	7.5-15	15-30	30-45
Rengam — Site 1 (RRIES)	374.3	158.9	63.6	38.8	51.8	20.7	16.9	10.6
Rengam — Site 2 (Muar Itam)	508.5	201.3	105.9	60.0	49.7	18.9	20.5	10.9
Rengam — Site 3 (Repah Est.)	621.5	300.2	113.0	63.6	49.0	23.9	17.4	9.7
Mean for Rengam	501.4	220.1	94.2	54.1	50.2	21.2	18.3	10.4
Sungei Buloh	981.7	445.0	211.9	123.6	46.9	20.3	20.5	12.3
Selangor	264.9	211.9	116.5	102.4	28.3	23.3	25.9	22.5
Munchong	293.1	236.6	158.9	105.9	28.2	22.1	28.8	20.9
Holyrood	953.5	490.9	166.0	130.7	47.6	23.0	16.3	13.1
Durian	794.6	293.1	141.3	88.3	52.4	18.7	18.1	10.8
Malacca	656.8	215.4	77.7	42.4	59.2	19.3	13.6	7.8
S.E. (±)	67.10	43.4	20.1	13.1	2.29	1.36	1.41	1.35
L.S.D. ($P < 0.05$)	190.7	123.6	56.5	38.8	6.5	3.8	4.0	3.8

field crops so profoundly that the root systems are scarcely recognisable as belonging to the same species. The results obtained in this study confirm Weaver's finding. RRIM 623 trees produced two and half times more feeder roots when grown on sandy soils, like Sungei Buloh and Holyrood series, than on clayey soils, like Selangor and Munchong series. In addition, besides the difference in absolute amount of feeder roots between soil series, the pattern of vertical distribution was also found to be significantly different. Such differences in root development could only be attributed to the inherent soil properties of the various soil series as other factors, such as cover management, fertiliser policy and climate, do not vary very much between the nine sampling locations. The relationship between the feeder root development and some of the soil properties was therefore examined.

Effects of soil properties on feeder root development. The literature on relationship between root growth and soil properties is voluminous. Therefore, it is not the purpose of this study to investigate in detail the effects of soil physical and chemical properties on root development of rubber. The aim here is to observe, on the basis of the data collected, whether there is any general relationship between feeder root development and some of the more important soil properties.

Significant positive correlations were found between fine sand content ($< 200\ \mu$ diameter) and root density at various soil depths *(Table 5)*. Correlations were better at the lower soil depth where possibly the interference by organic matter, soil microbial activity and other factors were less pronounced. In general, soils with higher fine sand content had higher root density and this could be due to the formation of more favourable soil

TABLE 5. LINEAR REGRESSIONS BETWEEN FEEDER ROOT DENSITY AND SOIL PROPERTIES

Soil property (x)	Soil depth (cm) 0 - 7.5	7.5 - 15	15 - 45
Coarse sand (%)	$y = 380.3 + 7.3x$ $r = 0.480$ NS	$y = 200.9 + 2.8x$ $r = 0.459$ NS	$y = 89.7 + 0.6x$ $r = 0.214$ NS
Fine sand (%)	$y = 205.9 + 19.7x$ $r = 0.717$ *	$y = 90.4 + 10.6x$ $r = 0.813$ **	$y = 24.0 + 4.6x$ $r = 0.809$ ***
Total sand content (%)	$y = 282.9 + 6.3x$ $r = 0.603$ (P 0.1)	$y = 150.4 + 2.8x$ $r = 0.619$ (P 0.1)	$y = 61.8 + 1.0x$ $r = 0.538$
Clay (%)	$y = 936.9 - 11.6x$ $r = -0.523$ NS	$y = 466.2 - 5.4x$ $r = 0.685$ *	$y = 185.8 - 2.0x$ $r = 0.675$ *
Organic carbon (%)	$y = 940.4 - 186.8x$ $r = -0.504$ NS	$y = 476.4 - 267.0x$ $r = -0.619$ NS	$y = 103.8 + 2.9x$ $r = 0.037$ NS

*$P < 0.05$ **$P < 0.01$ ***$P < 0.001$

structure, resulting in better aeration for root growth; or, it could be the trees' reaction to a soil with low moisture retention. Clay content was negatively correlated to root density, the correlation being significant at the lower soil depths. As in the case of fine sand, interference by organic matter, microbial activity and other factors in the surface soil layer probably did not cause the relationship between clay and root density to be significant. Correlation coefficients between root density and coarse sand or organic carbon contents were not significant for all the soil depths.

Since soil texture is an inherent property of soil, and cannot be altered easily by management practices, the above relationships could indicate the potential of soils for rubber cultivation. Soils with high clay contents will inhibit root development. Unless the soils contain sufficient amounts of sesquioxides and organic matter to offset this inhibition by generating good soil structure the growth of rubber trees will be affected. Examples of soils high in clay but low in sesquioxides can be found on soils like Batu Anam, Durian, Manik and Apek series. On the other hand, very clayey soils like Kuantan, Segamat and Prang series with high sesquioxide contents have stable soil structure which allows good root development.

The effects of other soil properties, such as bulk density, ped density and porosity, on root development between soil series are not readily assessable as many interacting factors, *e.g.* soil texture, organic matter, etc. come into play. Therefore, the study had to be confined to within soil series. Bulk density had the general tendency to increase with depth in each soil, but the increase was considered too small to explain the sharp drop in root density at the lower soil depth (*Tables 3* and *4*). For example, in Malacca series, bulk density increased by only 0.02 g/cc from the 0−5 cm to the 23−48 cm zone but the root density dropped about 95%. VEIHMEYER AND HENDRIKSON (1948) obtained some threshold bulk density values that limit root penetration; they were 1.75 g/cc for sands and 1.46 g/cc to 1.65 g/cc for clays. Since the bulk density values obtained for the various soils were far below the threshold values of Veihmeyer and Hendrikson it can be safely concluded that bulk density was not the limiting factor to root development in the soils under study.

For efficient exploitation of the soil, rubber roots must be able to penetrate not only spaces between soil peds but also the peds themselves. However, if the peds are dense enough to inhibit root penetration then, on the whole, root development in the soil would be restricted. EDWARDS *et al.* (1964) found that, for silt loams, a ped density of 1.80 g/cc is the threshold value above which corn roots are not able to penetrate the soil. Discrete ped density measurements made on the various Malaysian soils show that most of them had high ped densities in the subsoil with values near or greater than the threshold value quoted above. The only exception was Selangor series where subsoil ped density was betwen 1.22 g/cc to 1.32 g/cc. Therefore, ped density can be a limiting factor to root penetration in most of the soils studied.

Coarse structural peds in the soil have been shown to restrict root development (WIERSUM, 1962), and this is the result of reduction in interped porosity. In Rengam, Durian and Malacca series soils, coarse to very coarse structure are found in the subsoil (SOONG, 1971). Coupled with their high ped density values the subsoil conditions in these soils were, therefore, not favourable for root development and this explains the low root densities found in them.

Feeder root development of *Hevea* is influenced greatly by soil physical properties. Unfavourable physical conditions in the soil can lead to sparse rooting, and eventually cause poorer tree growth. Chemical properties have also been shown by CRIST AND WEAVER (1924) to influence rooting of crops. In their field experiments they found that in soils of high nutrient status the plants have shorter root, more branched and more compact than those grown in similar but less fertile soils. Since there are considerable variations in nutrient status of the common rubber-growing soils (GUHA AND YEOW, 1966) it would be of interest to study the effects of these nutrient variation on root development of *Hevea*. The information obtained can probably help the formulation of appropriate agro-management practices for the different soils.

Seasonal Variation on Feeder Root Development of Hevea.

Feeder root proliferation may be looked upon as a dynamic process responding to transient changes in nutrient and moisture availability and needs. Therefore, changes in soil and aerial environments will bring about changes in root development with consequent effects on the absorption of moisture and nutrients. In temperate countries, the root systems of deciduous trees demonstrate marked seasonal periodicity in their growth activity (HARRIS, 1926; ROGERS, 1939). The periodicity has been attributed principally to fluctuations in soil temperature and soil moisture content. However, NIGHTINGALE (1935) found that even with frequent irrigation and under apparently favourable soil temperatures, seasonal periodicity in the production of new roots still occurred. Therefore, factors other than those of soil environment are undoubtedly involved in causing these seasonal variations.

Table 6 shows the mean root densities of *Hevea* (RRIM 513 and RRIM 519) and percentage distribution of the roots at different soil depth at four sampling dates. These results were obtained by repeated sampling of the same trees on both Rengam and Sungei Buloh series soils. Differences in root densities between dates of sampling for each soil depth were highly significant. In the surface soil of Sungei Buloh series the highest root density was obtained in February and the lowest in August. For Rengam series soil the highest root density was in March and the lowest in December. In each soil, the amount of roots present at maximum activity was some 50% greater than that present at the lowest activity period.

In the subsoil layers, lowest root density also occurred in August for Sungei Buloh series soil and in December for Rengam

TABLE 6. SEASONAL VARIATION IN FEEDER ROOT DEVELOPMENT OF *HEVEA* ON TWO DIFFERENT SOILS

Date of sampling \ Soil depth (cm)	Mean root density (mg/1000 cc of soil)				Percentage distribution			
	0-7.5	7.5-15	15-30	30-45	0-7.5	7.5-15	15-30	30-45
Sungei Buloh series								
August 1970	668.3	258.0	108.4	56.8	53.3	20.3	17.0	9.4
November 1970	946.7	332.7	127.2	80.2	56.9	18.8	14.3	10.0
February 1971	997.2	297.3	95.8	68.8	63.7	17.5	10.9	7.4
May 1971	874.1	389.7	179.9	101.2	51.5	20.2	18.2	10.1
S.E. (±)	61.18	30.77	35.20	24.97	2.68	4.35	1.61	1.67
L.S.D. ($P < 0.05$)	176.6	88.8	101.6	72.1	7.9	12.8	4.7	4.9
Rengam series								
September	277.3	120.8	80.3	37.2	43.6	19.3	24.9	12.1
December 1970	243.4	87.6	47.0	30.9	50.2	17.5	19.3	13.0
March 1971	396.0	138.7	78.1	55.3	49.3	17.6	19.3	13.8
June 1971	346.7	221.6	141.1	98.8	33.0	20.9	26.5	19.6
S.E. (±)	20.26	23.08	14.46	14.91	1.32	1.27	1.48	1.70
L.S.D. ($P < 0.05$)	58.5	66.6	41.8	43.1	3.9	3.7	4.3	5.0

series soil. Peak root development, however, was not in February and March as in the surface soil layers but occurred three months later. The maximum amount of total feeder roots in the 45 cm soil depth occurred in May (Sungei Buloh series) and June (Rengam series). Therefore, it is expected that maximum uptake of moisture and nutrients is likely to take place during these periods.

Percentage distribution of feeder roots at each soil depth changed significantly over the season. In Sungei Buloh series soil the distribution of feeder roots was more superficial in February than in May. In February, 63.7% of the total root weight were in the surface soil layer compared to 51.5% in May. Changes in percentage distribution with depth was more obvious in Rengam series soil. In December and March about 50% of the feeder roots were in the 0 – 7.5 cm soil layer but in June only 33% of the roots were located in this layer. This indicates that the rate of root production at different soil layers changes with the season. Such changes will be discussed in relation to the demand of the tree for moisture and nutrients as well as environmental influence.

The rubber tree, being deciduous in nature, has an annual leaf-fall period of about three months (generally commencing in mid-December to February the following year) after which a period of active refoliation follows. During refoliation considerable amounts of water and nutrients were required for forming new leaves as well as for the increased metabolic activity in the tree. This heavy demand exerted by the tree, especially by the foliage, will therefore generate greater feeder root development. The relationship between density of canopy (measured as percentage light transmission) and feeder root density is shown in *Figure 2*. In the surface soil layer, maximum root develop-

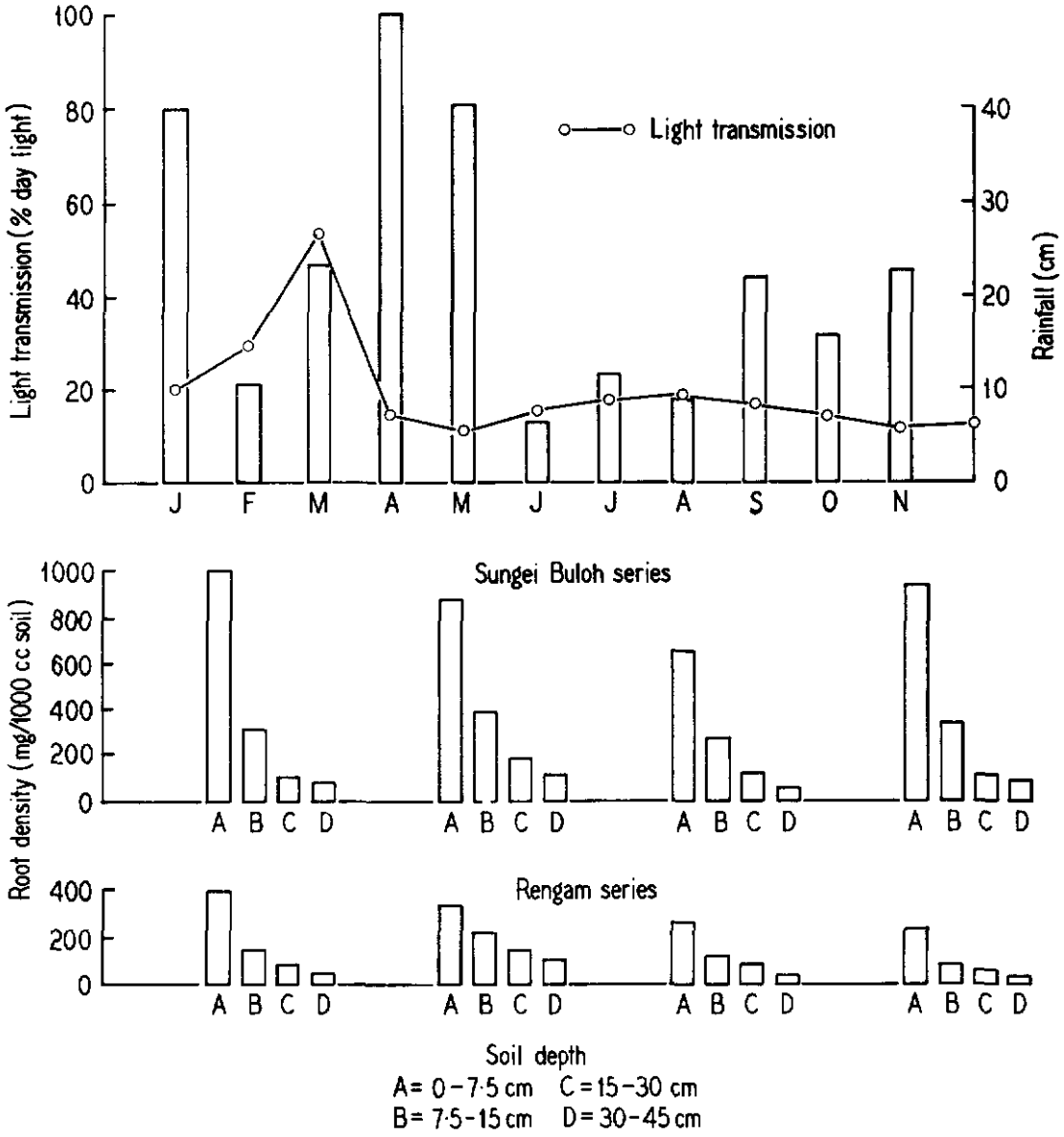

Figure 2. Relationships of feeder root density with density of canopy and rainfall.

ment occurred during the period when the tree was producing new canopy and this development persisted till March after which there was a decline to a minimum in August/September. There were indications that the tree began to develop new roots some time after December when the old leaves began to fall or had fallen. In the subsoil, maximum root development was reached only some time in May/June and declined to a minimum in the period August to December. The results show that during the period February to June the rubber tree has maximum uptake of water and nutrients, this being reflected in

the development of larger amount of feeder roots. The large uptake is required for leaf formation and expansion and also for increased metabolic activity. No clear relationship could be found with environmental factor like rainfall (*Figure 2*).

The above findings provide useful information for guiding the timing and method of fertiliser application. To secure the most efficient use of fertilisers they must be applied at the time when the trees' demand is greatest and also they must be applied in such a way that they are in contact with the roots. The above results suggest that the best time for applying fertilisers in mature rubber is around February or March since maximum surface root development occurs during this period. This has been confirmed in fertiliser trials by timing its application (PUSHPARAJAH AND TAN, 1972). Because of the superficial distribution of the roots the most appropriate method would be to broadcast fertiliser to ensure that it reaches the maximum number of roots. The results from this root study shows that the past recommendation on time and method of applying fertiliser to mature rubber have a sound basis. However, it must be pointed out that 'wintering' or leaf fall and refoliation periods do vary from place to place in Malaysia. Therefore, it is essential to adjust the manuring schedule according to the canopy condition of the trees, *i.e.* according to the onset of the leaf fall.

Effect of Cover Management on Feeder Root Development

The hot tropical climate in Malaysia necessitates a system of management that ensures minimum erosion and constant protection of the soil surface from the sun. In young rubber, the policy of growing cover plants has been practised rigidly since the post-war period. The value of different cover plants in enhancing rubber growth and improving the chemical properties of soil has been investigated by WATSON *et al.* (1964). The best effect was obtained with creeping leguminous covers comprising a mixture of *Pueraria pheseoloides, Centrosema* and *Calopogonium muconoides,* and the poorest effect was with *Mikania.* WATSON *et al.* (1964) also assessed the mean root densities of both cover plant and rubber tree in the surface 7.5 cm of soil. Differential manuring treatments had also been included in the cover plant experiments and this included (a) fertilisers applied to tree rows and not to cover and (b) fertilisers applied to cover only.

The results, adapted from WATSON *et. al.* (1964) in *Table 7*, show that there was more vigorous feeder root development under legume cover than under grass or *Mikania* cover. Root density under *Mikania* was about half that under legume. Such differences in feeder root development of *Hevea* under different cover system could be attributed to (a) competition for moisture and nutrients with roots of cover plant and (b) the release of toxic substances from the cover plant, causing suppression in root growth.

On the basis of root density value there was least competition under legume cover and the highest under grass cover. The total amount of roots of grass was three times that of legumes. Although *Mikania* has had a lower root density than grass it however caused greater suppression of rubber proliferation. WONG (1964) found that this suppression of rubber root growth was caused by the exudation of growth inhibitory substances which include phenolic and flavonoid constituents by the roots of *Mikania*.

Competition for nutrients is also one of the reasons for supressed root development. RICHARDSON (1953) suggested that reduction of root growth in tree influenced by grass and other herbaceous species is due to the latter's competition for nitrogen. On this basis root growth should be enhanced if additional fertilisers are applied to offset the competition. The results in *Table 7* show that fertilisers applied to rubber rows encouraged

TABLE 7. EFFECTS OF COVER MANAGEMENT ON FEEDER ROOT DEVELOPMENT OF *HEVEA*

Type of roots	Cover treatment								
	Legume creepers			Grass			*Mikania*		
	r	*c*	S.E. (±) (L.S.D. P < 0.05)	*r*	*c*	S.E. (±) (L.S.D. P < 0.05)	*r*	*c*	S.E. (±) (L.S.D. P < 0.05)
Cover plant root (mg/1000 cc of soil)	93.9	98.3	24.23 (83.8)	319.4	291.0	21.63	215.0 (97.3)	285.5	31.52 (109.1)
Rubber root (mg/1000 cc of soil)	623.1	401.8	59.17 (178.9)	329.6	280.9	59.17 (178.9)	251.1	263.7	59.17 (178.9)

r = fertilisers applied to tree rows and not cover
c = fertilisers applied to cover only
Adapted from WATSON *et al.*, 1964

more vigorous feeder root proliferation of the rubber tree than fertilisers applied to cover only. The order of difference in feeder roots due to the fertiliser treatments was more than 50% under legume cover and about 17% under grass. Under *Mikania* there was practically no difference in rubber root density. This therefore shows that a proper method of manuring can generally offset competition for nutrients between cover and rubber trees.

All the cover plant experiments carried out in the last two decades established that creeping leguminous plants are superior to other types of cover in improving growth of young rubber trees. They improve the physical and chemical properties of soil (SOONG AND YAP, 1975), creating, as a result, a more favourable soil environment for the roots, and hence allow the rubber trees to grow better. Even when the legumes die off their residual effects persist. MAINSTONE (1969) observed better proliferation of rubber roots in the interrow of mature rubber where there had been leguminous rather than naturally established non-leguminous covers. Proper cover management is therefore essential for optimising conditions for the growth of rubber.

CONCLUSIONS

Root sampling, using the 'Auger Method' carried out on four clones of *Hevea brasiliensis* showed that there were significant clonal differences in feeder root development. A vigorous clone like RRIM 605 had about 80% more feeder roots (by weight) than a slow growing clone like RRIM 513 in soil depth of 45 cm. The greatest difference in root proliferation between clones was in the subsoil. It appears, therefore, that the adaptability of certain clones over a wide range of soil situations could be due to their genetic ability to produce an efficient feeder root system.

The root study conducted on RRIM 623 clones, growing on seven different soil series, showed that there were significant differences in feeder root development between soils. Sandy soils like Sungei Buloh and Holyrood series lead to about two and half times more feeder roots than clayey soils like Selangor and Munchong series. In the vertical distribution pattern it was found that

in most soils, with the exception of Selangor and Munchong series, the greatest root proliferation was in the 0−7.5 cm soil layer, and the proliferation decreased rapidly with depth until at the 30−45 cm soil layer; the amount of feeder roots was only about one-tenth of the total amount present in the whole 0−45 cm soil depth. The results show that the subsoils of most of the Malaysian soils are less thoroughly explored by rubber roots, particularly those with coarse structural units, high ped density or compact laterite horizon.

Feeder root densities in the various soils were found to be significantly correlated with the fine sand and clay contents, positively with fine sand and negatively with clay content.

Seasonal variations in feeder root development were also significant. Maximum root development occurred in February/March, corresponding to the period of peak uptake of moisture and nutrients by the tree for foliage production and increased metabolic activity. Minimum root development was around August to December when the leaves were senescent or ready to fall off. Therefore, seasonal development in feeder roots is determined by the demand of the tree for moisture and nutrients.

Cover management has been found to exert a great influence on root development of young rubber trees. Of the three types of cover plant tested, leguminous creeping covers gave better rooting than grass or *Mikania*. Poorest feeder root development of rubber was found under *Mikania* cover thus emphasising the need for a good leguminous cover.

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