NOTES ON TROPICAL SOILS WITH SPECIAL REFERENCE TO MALAYAN SOILS FOR RUBBER CULTIVATION*

BY

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Soil is the product of climate and vegetation acting on rocks. The climatic factors are both mechanical and chemical and, in the humid tropics, the main factor is chemical, in the form of rain water carrying dissolved carbonic and nitric acids. Erosion is the chief mechanical factor.

The following remarks apply only to soils of the humid tropics.

The continual high rainfall and temperature facilitate comparatively intense chemical action and rock weathering. Rocks, which in the tropics are weathered to a depth of thirty to forty feet, are in temperature countries either bare or covered with a very shallow layer of soil. This formation of deep soil is however, accompanied by removal of large quantities of plant food by leaching.

With the first signs of weathering, lower forms of plants appear and, as weathering advances, these are replaced by higher plants, and eventually the vegetation takes the form of the tropical rain forest found in Malaya.

Before the heavy leaching has removed the bulk of the plant nutrients, a certain amount is taken up by the early vegetation, also a certain amount of plant food is brought up from lower layers by deep rooting forest plants; much of this plant food is returned to the surface layer by decaying vegetation and is taken up again by succeeding vegetation.

It is estimated that in a tropical rain forest the yearly production of fresh organic matter is about one hundred tons per acre, yet the depth of forest litter is only a matter of an inch or so, and the depth of soil humus is usually not more than four inches. This is due to the fast rate of organic decomposition which, even in heavily shaded forest, is almost as fast as formation. In this way a continuous forest cycle is formed with young plants living mostly on the debris from older ones. In addition a certain amount of atmospheric nitrogen is added to the soil by nitrogen-fixing bacteria, and also a certain amount of nitrogen is deposited in the form of nitric acid in the rains following thunder-storms.

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The soil usually found underlying primeval forest, therefore, consists of a thin layer of humus, usually not more than six inches deep, overlying a leached soil, many feet deep. The "inexhaustible fertility" of tropical soils inferred from the luxuriant forest vegetation is seldom found.

There are areas throughout the tropics where more permanently fertile soils occur. These are either deep alluvial clay soils, formed from the weathered products of igneous rocks, or soils formed as the result of recent volcanic activity. Examples of the latter are found in Netherlands India and in the West Indies. In the West Indian Island of St. Vincent a particularly striking example occurs. In 1902 a large portion of the north half of this island was covered with ash from eruptions of the Soufriere, and in a few years, crops were re-established on many of the damaged estates. When visiting the island in 1933 the writer was shown over an excellent coconut plantation on the lower slopes of the Soufriere where, owing to the high content of fresh minerals still available for decomposition, the soil will remain fertile for many years.

Geology and Topography

Next in importance to climate in deciding soil type are the geological and topographical features of the land.

In a country of uniform climate, soils formed in situ are closely related to the underlying rocks, as will be seen later when Malayan soils are considered.

Rocks are of three main types.—

1.	Igneous Rocks.	These are crystalline and volcanic rocks such as granite, andesite and basalt. These rocks are fairly uniform as are also soils formed from them.
2.	Sedimentary Rocks.	Limestones, and rocks formed from the weathered products of igneous rocks which have been transported and deposited in the form of sediments, such as sands, silts and clays. As would be expected, soils formed from these deposits are very variable.
3.	Metamorphic Rocks.	When sediments come under the influence of heat and pressure metamorphic rocks are formed and, as in the case of sedimentary rocks, are very variable, soils formed from them being often poor. Quartzite rocks belong to this class.

Examples of soils formed from each of these rock types will be given in the discussion on Malayan soils.

SOIL FERTILITY

The agricultural value of a soil depends on its position and fertility; a highly fertile soil in an inaccessible position is naturally useless.

Soil fertility depends on the following main factors:

1. Water supplying capacity
2. Nutrient supplying capacity
3. Oxygen supplying capacity
4. Root space
5. Absence of harmful factors
6. Temperature

Plant growth is limited to a greater or lesser extent by each of the above factors and, in assessing the fertility of a soil, or in recommending any treatment to improve fertility, each of the above factors must be considered.

The relative importance of each of the factors is greatly influenced by the crop in question, but for most tropical crops the water relationships of a soil are of paramount importance. Rubber, for example, must have an abundant water supply, yet it will not stand waterlogging.

Root space is closely bound up with the water question.

A satisfactory method for assessing the value of a soil for agricultural development, or its suitability for a particular crop, has been evolved by the Soils Department of the Imperial College of Tropical Agriculture, Trinidad, under the direction of Professor F. Hardy, and is roughly as follows.

Soil profiles are exposed in pits six feet deep which are carefully described as to colour, texture, moisture, root development, depth of water table if present; particular attention is paid to the occurrence or otherwise of pans, stones, sand layers etc. The surrounding vegetation is carefully described. Soil samples are taken from different layers, usually 8 to 12 in number, and examined in the laboratory. Determinations are made which aim at measuring the texture, moisture relationship, nutrient supply and the detection of harmful factors if present. The values obtained are plotted to scale on profile cards by using suitable colours; samples of the soil, finely ground, are mixed with clear varnish and painted on the cards opposite the corresponding set of colour values. (*Vide* Figs. I—V facing page 42).

Where any particular crop is concerned pits are examined and soil samples are analysed from as many representative areas as possible, especially from those which are known to be good and those which are known to be bad. All available information as regards growth, yield, quality of crop and susceptibility to disease on each site is noted. Where any particular plant food deficiency is indicated manurial experiments are laid down to test this. By this means it is possible to determine the soil environment best suited to the crop in question and, knowing what is required, to improve poor environments by means of manures or cultivation if it is economic to do so.

Analyses of leaves of various crops have also recently been used in conjunction with soil investigations and field experiments; the results have been found very useful in helping to solve fertility problems in the cultivation of such crops as cocoa and citrus.

A large amount of data has been collected according to the above methods from the various West India Islands, British Guiana and British Honduras, and the soil conditions best suited to the growth of such crops as sugar cane, cocoa, citrus, bananas and coconuts have been defined. Almost every type of soil found in the humid tropics has been studied, either from the point of view of agricultural development, or in relation to one or other of the aforementioned crops.

Soils such as many of the inland soils of Malaya have been found to be of low permanent fertility, with the bulk of the nutrients confined to the top layers. When the forest is cleared and these soils are exposed for agricultural development, deterioration is rapid, and soon they require continued application of manures, if economic yields are to be obtained.

The importance of soil examination, before areas of humid tropical soils are opened up for agricultural development, has been emphasised by this and other tropical soil work. Owing to the great variation and general low permanent fertility of humid tropical soils, many areas have been planted with various crops which are very unsuitable. Dr. P. Vageler who has had twenty years' experience in tropical soil work in various countries, estimates that 75 per cent of all failures in agricultural enterprises in the tropics is due to planting on unsuitable soil, because

i. The soil is not worth cultivating.
ii. The soil is not suited to the crop.
iii. The soil requires heavy outlay on manures.

The position is usually made worse by the fact that early growth is good even on poor soils, but is generally followed sooner or later by deterioration or failure of the crop.

In days of high prices such facts are not apparent, but when prices settle down as they eventually do in the case of most crops, it becomes a case of small profits and large turnover, entailing low cost of production, where high yield per acre and low cultivation costs—which are only obtained on reasonably good soils, properly treated—are all important.

Malayan Rubber Soils

The following observations on Malayan rubber soils are of a preliminary nature. They are derived from notes made from the examination of some 200 soil profiles in different parts of Malaya, during the past six months by Hardy's methods. All available information concerning the rubber trees on each soil type has been collected, and this has been considered in relation to profile description, and soil and leaf analyses, carried out by the analytical staff of the Soils Division.

The following arbitrary scheme for assessing soil factors is derived from a similar one formulated by Hardy for West Indian Soils, and has been modified to suit Malayan conditions in respect of rubber cultivation.

It will probably be necessary to revise some of these values when results are available of field experiments on rubber which are being laid down on the various soil types.

Index of Texture (I.T.)

60 — 56	Heavy clay
55 — 41	Clay
40 — 31	Silt
30 — 21	Loam
20 — 11	Sand
10 — 1	Light sand

Reaction (pH)

9.0 — 8.0	Very highly alkaline
7.9 — 7.6	Highly alkaline
7.5 — 7.1	Alkaline
7.0	Neutral
6.9 — 5.5	Slightly acidic
5.5 — 4.0	Acidic
4.0 — 3.0	Highly acidic
3.0 — 2.5	Very highly acidic

Organic Matter (O.M.)

per cent.	
8.0 — 5.0	Very high
5.0 — 3.5	High
3.5 — 2.5	Medium high
2.5 — 1.5	Medium
1.5 — 1.0	Medium low
1.0 — 0.5	Very low
0.5 — 0.0	Negligible

Total Nitrogen (N)

per cent.	
0.55 — 0.35	Extremely high
0.35 — 0.25	Very high
0.25 — 0.15	High
0.15 — 0.12	Medium high
0.12 — 0.08	Medium
0.08 — 0.05	Medium low
0.05 — 0.03	Low
0.03 — 0.00	Very low

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from a profile exposed in a road cutting at the 14½ mile post on the Kuala Lumpur—Tanjong Malim Road, and is as follows:—

Depth	
0 — 6 ins.	Dark brown humic loam
6 ins.— 3 ft.	Light brown sandy loam
3 ft. — 6 ft.	Yellow sandy loam
6 ft. —13 ft.	Red sandy loam with very coarse sand grains
13 ft. —17 ft.	Red decomposed rock and soil
17 ft. —19 ft.	Rotten rock
19 ft. downwards	Hard granite rock.

Conductivity ("Nutrients")

300 — 100	Very high
100 — 70	High
70 — 50	Medium high
50 — 40	Medium
40 — 30	Medium low
30 — 20	Low
20 — 0	Very low

Available Phosphate (P_2O_5)
(Truog N/100 H_2SO_4)

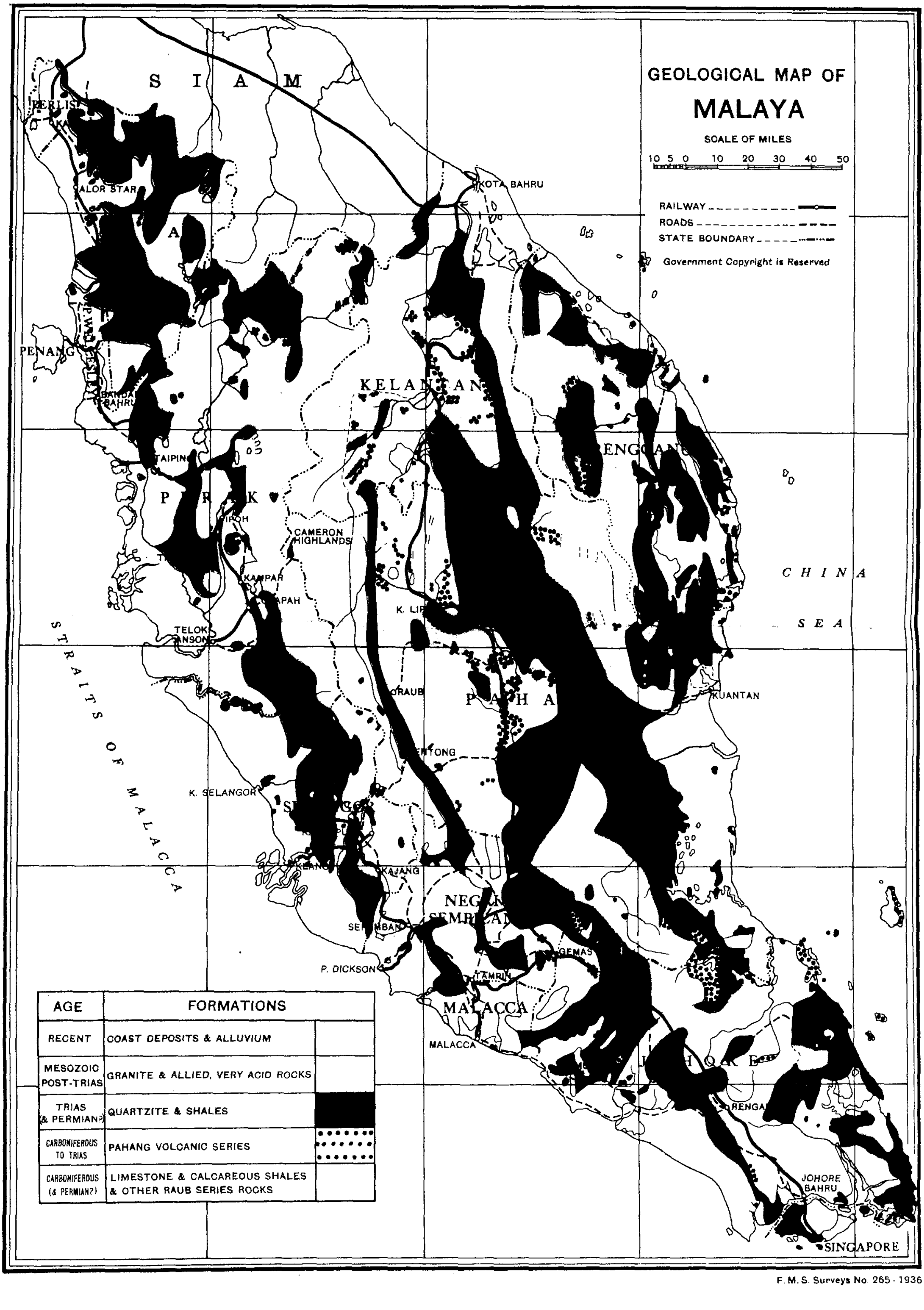
Parts per million	
100 — 50	Very high
50 — 40	High
40 — 30	Medium High
30 — 20	Medium
20 — 10	Low
10 — 0	Very low

Available Potash (K_2O)
(N/2 Acetic acid)

Parts per million	
1000 — 500	Extremely high
500 — 350	Very high
350 — 280	High
280 — 200	Medium high
200 — 120	Medium
120 — 80	Medium low
80 — 50	Low
50 — 20	Very low
20 — 0	Extremely low

" Nutrients " values which exceed 700, as is the case in the lower layers of some coastal clay soils, probably indicate the presence of free acid or a high concentration of salts, both of which inhibit root growth. Values over 700 can be taken to indicate bad drainage conditions.

The phosphate status of Malayan soils is puzzling. When Truog's method, which is used in the West Indies for determining available phosphate, is applied to these soils, values of less than one part per million are obtained in the case of all inland soils. Hardy regards values of less than twenty parts per million as being low, and it would appear that the phosphate status of Malayan soils is very low. As a result of the very low values obtained the strength of the extracting acid has been increased five times, from 0.002 to 0.01 per cent sulphuric acid and even then the values obtained for inland soils are mostly below twenty, while virgin soils do not seem to be appreciably better in this respect than cultivated soils. Coastal clay soils as a



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rule are much higher in available phosphate than are inland soils, and this high soil phosphate is reflected in a high phosphate content of rubber leaves from rubber trees growing on coastal soils, as compared with a low phosphate content in leaves from trees growing on inland soils.

The phosphate question is receiving special attention in the Soils Division, where new methods for determining available phosphate are being investigated and field experiments are being laid down to test the findings of the soil analyses.

Geology and Topography of Malaya

The topography of Malaya is mountainous with the ranges running mostly in a North-South direction, the hills rising sharply from the plains, and consequently the rivers remove much soil material, which is deposited at lower levels. Scrivenor's book and map on the geology of Malaya considerably simplifies soil work in this country, and all references to Malayan geology are taken from this work. The chief geological formations found in Malaya are :—

1. Granite
2. Quartzite
3. Limestone
4. Pahang Volcanic Series
5. Coastal Deposits and Alluvium

The distribution of the above formations is shown in the Geological Map.

Granite Soils

According to Scrivenor the average depth to which granite is weathered is about 30 feet. The weathered product is a yellow, orange or red, soft mass, running from soil through soft, rotten rock to hard rock. Sometimes the depth of weathering is much shallower and sometimes the weathered product changes abruptly from soil to hard rock and, in some cases, boulders are found which are very resistant to weathering.

An example of this typical deep weathering of granite is seen from a profile exposed in a road cutting at the 14½ mile post on the Kuala Lumpur—Tanjong Malim Road, and is as follows :—

Depth	0 — 6 ins.	Dark brown humic loam
	6 ins.— 3 ft.	Light brown sandy loam
	3 ft. — 6 ft.	Yellow sandy loam
	6 ft. —13 ft.	Red sandy loam with very coarse sand grains
	13 ft. —17 ft.	Red decomposed rock and soil
	17 ft. —19 ft.	Rotten rock
	19 ft. downwards—Hard granite rock.	

For agricultural purposes, as far as rubber cultivation is concerned, only the top 6 feet of soil need be considered. As can be seen from the above profile the top 6 feet is a uniform textured sandy loam soil, drainage and aeration are good and the soil contains sufficient clay to hold a considerable amount of moisture. There are no pans or hard layers which would hinder root development. The nutrient status of this soil is only medium, especially in regard to phosphate and nitrogen, and the bulk of the nutrients are concentrated in the top thin humic layer.

According to Vageler, for good growth and yield of rubber on soils where the water table is deep, as in the case of most upland soils, 5 feet of uniform soil of good texture is necessary. Observations on rubber in Malaya are in agreement with this.

Rubber trees appear to do very well on granite soils if planted on virgin land; growth and yield are usually very good, but the rate of bark renewal, and consequently the yields in many cases fall off when the rubber is about 20 years old. The good initial growth and yield of rubber on these soils is probably due to reasonably good texture, combined with a fair supply of nutrients in the virgin soil. Deterioration is mostly due to the loss of a large amount of the top humic layer from erosion and exposure to the sun. Granite soils should be kept covered at all costs in order to prevent erosion and baking of the top soil. The chief effect of cover is to retain what is already in these soils, and to maintain good moisture conditions by preventing water running off and by inducing percolation.

On deteriorated granite soils, the value of "forestry methods" as practised on Malayan rubber estates is limited from the point of view of adding organic matter and nutrients.

In Malayan forests where 100 tons of fresh organic matter per acre per annum are produced, and where shade is much denser than on a rubber estate, the depth of humus is seldom more than four inches, and often less, after years of forest growth. On this account it is suggested that the amount of plant food added even by good forestry cover is very small, especially in regard to minerals; for this reason it is suggested that manuring combined with forestry is necessary on deteriorated soils. The effect of the manures will be greatest if they are added before much deterioration in the rubber has set in. It is much easier to keep rubber trees in good condition with manures and forestry, than to rejuvenate deteriorated rubber, and should cost much less. Nitrogen and phosphate are necessary, and phosphate is best applied in the form of large dressings of a good type of rock phosphate. Phosphatic manures should be well incorporated with the top layer of soil.

In steep ravines granite soils are usually white and sandy and of poor quality, but in valleys they are usually deep and fairly fertile.

As has already been stated, granite soils in the virgin state produce very good growth of rubber trees and, in view of the fact that unless they are well covered deterioration is rapid and also that considerable damage is done by burning, the possibility of planting on these soils, or in fact on all inland soils, without burning, is worth considering. In this way the top humic layer will be maintained and a good forest cover can be established from the beginning.

Granite soils carrying good rubber trees are found in parts of South Kedah, North and Central Perak, Selangor, Negri Sembilan, especially in the Labu Valley and small areas in Central Johore.

The poor rubber trees on much of the granite in Malacca and South Johore are due to previous cultivation and erosion.

TABLE I

Some Granite Profiles

Lower depth inches	Sand per cent	I. T.	pH	Nutri-ents	O.M. per cent	N per cent	P_2O_5 p.p.m.	K_2O p.p.m.	Remarks
3	53	23	4.6	33	3.6	0.13	9	229	Old rubber trees well grown and yields were good but bark has deteriorated badly. Needs to be kept covered and should have been manured earlier.
6	43	25	4.6	21	2.2	0.07	7	149	
12	43	26	4.7	22	1.7	0.05	9	181	
24	43	26	4.7	21	1.6	0.05			
3	74	4	4.3	62	4.6	0.12	6	183	Sandy granite soil, old rubber trees fairly good but will need manuring. Low phosphate. Although this soil is high in sand it contains a fair amount of clay.
6	65	9	4.4	40	3.3	0.08	8	143	
12	64	7	4.2	72	2.7	0.05	7	159	
24	63	10	4.2	45	2.4	0.05			
36	58	13	4.2	58	2.4	0.05			
48	54	12	4.2	74	2.1	0.04			
60	52	14	4.2	63	2.2	0.03			
3	58	10	4.2	105	8.4	0.21	5	288	Granite forest soil, high "nutrients" and potash. Note sharp drop in nitrogen below 3 ins. Low phosphate.
6	56	12	4.0	187	8.2	0.08	8	280	
12	52	16	4.0	249	3.3	0.06	6	265	
24	56	14	4.0	199	2.5	0.06			
36	50	14	4.5	218	2.4	0.05			
54	43	18	3.8	353	2.1	0.03			
72	50	15	3.8	374	2.0	0.03			
3	49	20	3.6	202	5.4	0.21	9	412	Granite forest soil, "nutrients" good. Low phosphate.
6	40	19	3.8	161	3.2	0.12	7	203	
12	47	16	4.0	144	1.8	0.10	6	229	
24	45	19	4.0	148	1.9	0.07			
36	50	16	4.0	177	1.0	0.05			
54	50	11	4.1	107	1.1	0.05			
72	42	18	4.0	116	1.0	0.06			

Note the high "Nutrients" and potash (K_2O) values in forest soils as compared with cultivated soils.

QUARTZITE SOILS

In contrast to granite, quartzite rocks are very variable as are also soils formed from them; according to Scrivenor, they are more resistant to weathering than granite.

In general quartzite soils are low in plant food especially in respect of nitrogen and phosphate, but may be better in this respect than granite soils. The same general remarks as to deterioration, forestry methods and manuring apply to these soils as to granite.

A more serious objection to quartzite soils, than their low nutrient status, is the frequent occurrence in these soils of an undesirable texture.

The soil profiles already examined show that the following types of quartzite soils occur on Malayan rubber estates, although the division between the different types is not always distinct.

1. *Yellow-red or red loamy soils,* of good depth and texture, and free from sand layers or layers which impede root development. These soils are often better than the granite soils already described. Examples of these soils have been found in South Kedah, parts of North and Central Perak and North Selangor.
2. *White or grey sandy soils,* devoid of any crumb structure. Sometimes these soils are dark on top, giving the impression of having a high content of organic matter, but this is usually due to carbon. The sand increases in coarseness at about five feet and is sometimes cemented into hard pans.

   Rubber on this type of land is usually stunted in growth, yields are low and bark renewal poor, foliage is usually sparse and yellow. Often strips of this soil run through good soil such as (1).

   Water as well as plant food on these soils is a limiting growth factor and, on this account, manures in most cases are of doubtful economic value. A cover is most important. If manures are used on these soils a complete manure is necessary; the potash content of leaves of rubber growing on these soils is very low in comparison with that of leaves from other inland soils.

   As rubber trees on these soils are usually the poorest on an estate, these areas are often included in replanting programmes, but this procedure is not to be recommended, and in every case replanting on these soils should at first be on an experimental scale. Areas of these soils are found in South Kedah, South Perak and in the Sungei Buloh district of Selangor.
3. *Yellow-red or red loams resembling* (1), but with laterite* stones in the top six feet. These soils are again of two classes.

* In all cases the term laterite is used with the popular Malayan meaning.

(*a*) The laterite stones are not in the form of a compact layer. These soils are usually almost as good as (1). They are found throughout Malaya where quartzite rocks occur.

(*b*) The laterite is in the form of a hard compact layer, likely to check the development of the tap-root. If the laterite layer is about 3—4 feet from the surface, the rubber trees are fair but not good. If the layer is within 18 ins. of the surface, the trees are poor and for rubber cultivation these soils are of doubtful value.

Areas of these soils occur in Central Kedah, and in parts of Selangor, Negri Sembilan and Johore.

TABLE II

Some Quartzite Profiles

Lower depth inches	Sand per cent	I. T.	pH	Nutri-ents	O.M. per cent	N per cent	P_2O_5 p.p.m.	K_2O p.p.m.	Remarks
3	48	20	3.7	260	6.6	0.30	6	491	Forest soil on good type of quartzite. Texture good and no pans. Potash high but phosphate low.
6	46	21	3.8	211	3.1	0.16	4	415	
12	45	22	3.9	274	3.4	0.12	4	321	
24	47	22	4.0	175	2.1	0.09			
36	45	20	4.0	209	1.6	0.07			
48	43	27	4.0	170	1.6	0.07			
60	42	22	4.2	139	1.4	0.05			
72	48	19	4.2	125	1.4	0.04			
3	32	33	4.2	20	3.3	0.12	8	208	Old rubber trees fairly good; some laterite but not compact. Low phosphate.
6	27	29	4.3	20	1.3	0.07	5	127	
12	26	28	4.2	14	1.3	0.06	6	140	
24	39	22	4.2	15	1.2	0.05			
36	53	13	4.6	11	1.1	0.03			
48	45	18	4.4	12	1.0	0.03			
60	38	20	4.5	11	1.0	0.03			
3	45	27	5.1	75	11.5	0.30	11	170	Old rubber trees very good. Good quartz-ite, no laterite. Note high N and O.M. in surface soil.
6	40	24	5.0	67	6.4	0.23	11	158	
12	73	3	5.0	45	1.3	0.08	10	100	
24	70	7	5.0	25	1.4	0.07			
36	68	8	4.9	30	0.8	0.05			
54	61	10	4.9	38	0.4	0.04			
72	60	10	5.2	25	0.4	0.03			
3	89	0	5.3	26	1.3	0.08	9	113	Old rubber trees very poor. Poor sandy soil. Note very low N and O.M.
6	90	0	5.5	34	1.1	0.04	9	115	
12	93	0	5.3	31	0.9	0.04	9	102	
24	92	0	5.4	24	0.6	0.03			
36	93	0	5.4	33	0.6	0.02			
54	94	0	5.4	37	0.5	0.02			
72	96	0	5.5	44	0.2	0.02			

Note the high "Nutrients" and potash (K_2O) values in forest soils, as compared with cultivated soils and the sharp decrease in nitrogen with depth.

4. *White or yellow clay soils.* These soils carry fair rubber trees if the clay is not too heavy and compact as is the case with the higher level yellow clays. In the case of the low level, stiff, white clays the rubber trees are poor, growth is slow and bark is hard with poor renewal. Nitrogen and phosphate will probably improve the trees on these soils but, in addition to manuring, every effort should be made to improve the texture. A cover is necessary to prevent the hard drying-out of the top soil, which occurs if these soils are exposed. In the case of young rubber trees continued digging in and manuring of the cover, although expensive, might repay the extra cost. Large areas of these soils occur in the Bahau district of Negri Sembilan and in parts of Pahang.

LIMESTONE SOILS

(*a*) *Free lime in surface soil.* These soils are of very limited occurrence; they are found in Central Perak near Ipoh. They are chocolate brown in colour and have a good loamy texture. The pH may be over 8 which makes them unsuitable for rubber cultivation.

Leaves from trees growing on these areas have abnormally high calcium contents. Heavy dressings of sulphur might be of value in improving these soils but would probably not be economic.

(*b*) *No free lime in surface soil.* These are red loamy soils and their value varies according to the amount of laterite they contain. If there is only a small amount of laterite and this is not in a compact layer, the soil is fairly fertile and grows good rubber trees. In most cases however they contain much laterite which greatly reduces their value.

The nutrient status is fair but in most cases rubber trees growing on these soils will benefit from applications of nitrogen and phosphate.

When, as has happened on large areas, erosion has greatly reduced the already thin layer of laterite-free topsoil, the resulting soil is very poor.

Areas of these soils are found in South Negri Sembilan, Malacca and Johore.

Often the limestone is covered by a cap of quartzite rock and the resulting quartzite soils are similar to 3 and 4, already described.

TABLE III

Some Limestone Profiles

Lower depth inches	Sand per cent	I. T.	pH	Nutrients	O.M. per cent	N per cent	P_2O_5 p.p.m.	K_2O p.p.m.	Remarks
3	37	32	4.3	34	3.9	0.18	12	179	Old rubber trees fair; good profile for limestone, laterite is not compact.
6	32	30	4.3	23	3.3	0.15	9	140	
12	33	34	4.3	21	2.6	0.12	9	119	
24	33	31	4.3	19	2.0	0.08			
36	48	19	4.5	19	1.6	0.06			
48	41	31	4.6	16	1.2	0.05			
60	36	24	4.8	11	1.2	0.05			
3	23	25	3.8	212	5.2	0.11	7	431	Forest soil, high "nutrients." Low phosphate. Compact laterite layer below 24 ins. will retard growth.
6	22	23	3.8	229	4.5	0.10	7	375	
12	31	28	4.4	144	4.3	0.13	6	431	
24	7	41	4.1	101	4.0	0.09			
36	7	42	4.1	169	2.8	0.08			
48	9	42	4.2	141	2.8	0.07			
6			8.4	138	2.3	0.14	12	343	Lime in surface soil; note very high pH. Rubber trees poor and chlorotic.
24			8.6	138	2.5	0.18	15	389	

Pahang Volcanic Soils

The rocks from which these soils are formed occur mostly in Pahang and Kelantan, and as yet have not been developed for rubber cultivation to any extent. Small areas are found in Johore; an outcrop occurs along the Buloh Kasap—Segamat Road. This soil is formed from basalt and is deep brownish-red in colour; it has an excellent loamy clay texture, is free from stones and is uniform to at least 15 feet. The rubber trees on this area are old, but are still very high yielding, and bark and foliage are very good. The trees are very large resembling those on good coastal clays, root development is excellent, many fine roots being found at six feet, which is very unusual. Root disease is fairly abundant. The dry rubber content of the latex from this area is considerably higher than that of the adjoining areas. The plant food content of this soil is high except in the case of available phosphate, but the value shown for phosphate may be too low. Phosphate is readily fixed in this type of soil in a comparatively insoluble form, and it is probable that some of this fixed phosphate is available to the rubber roots.

The relatively high organic matter and nitrogen values, even at five feet, are worthy of note.

TABLE IV

A Profile on a Basalt Rock of Pahang Volcanic Series

Lower depth inches	Sand per cent	I. T.	pH	Nutri-ents	O.M. per cent	N per cent	P_2O_5 p.p.m.	K_2O p.p.m.	Remarks
3	20	32	4.3	215	8.6	0.24	5	365	Old rubber trees very good, but much root disease. Very good texture and uniform to 15 feet. Very deep lateral root development.
6	13	38	4.2	184	3.7	0.15	6	354	
12	15	37	4.2	167	3.5	0.10	5	314	
24	12	37	4.3	198	3.1	0.10			
36	12	38	4.3	210	2.5	0.10			
48	11	40	4.5	149	2.7	0.08			
60	12	40	4.6	140	2.5	0.07			

Area under cultivation since 1908. Note high "nutrients" even at 5 ft. N. and O.M. good throughout the profile. Low phosphate due probably to high fixation.

Very good inland soil.

DETERIORATION OF INLAND SOILS DUE TO PREVIOUS CROPPING

Where inland soils have grown other crops before being planted with rubber trees they are considerably poorer and grow much poorer trees than the corresponding virgin soil. Deterioration is due to cultivation and exposure, as well as to removal of plant food by the previous crops. The plant food requirements of tropical crops vary greatly; pineapples remove large amounts of plant food, especially potash. It is estimated that a pineapple crop removes annually the equivalent of 5 cwts. of sulphate of potash per acre from the soil.

ALLUVIAL SOILS

(*a*) Inland

These soils have not yet been investigated to any extent by the profile method; they are found chiefly in Central Johore and North Kedah. Variation seems to be considerable, as would be expected, and they resemble quartzites.

(*b*) Coastal Deposits

Coastal soils are conveniently divided into two types,

(1) Clays (2) Peats

(1) CLAYS

Clays are the most important of this group, as they constitute the largest area of coastal rubber soils. These soils vary greatly both in texture and chemical composition. They are the richest soils in Malaya and, with reasonable treatment, should remain fertile for many years.

These soils are usually grey or grey-brown in colour above the water table, the texture is usually fairly open for clay soils and the plant food content is very good. The pH is usually above 4 which is quite suitable for rubber cultivation. In the zone of fluctuating water table they are bluish with red or yellow mottlings and show increased acidity. The layer permanently below water is blue with a very low pH, the very high "nutrients" figure probably indicating the presence of free acid.

TABLE V

Some Coastal Alluvium Profiles

Lower depth inches	Sand per cent	I. T.	pH	Nutrients	O.M. per cent	N per cent	P_2O_5 p.p.m.	K_2O p.p.m.	Remarks
3	19	41	4.4	65	8.0	0.27	75	396	Old rubber trees very good. "Nutrients" high and soil well drained, no acidity increase at 36 ins. Rubber trees replanted on similar soil without manuring are very good.
6	22	40	4.3	47	6.4	0.25	71	333	
12	11	40	4.0	47	6.1	0.21	32	330	
24	7	41	4.0	58	4.5	0.15			
36	19	33	4.0	101	2.3	0.09			
3	11	42	4.1	56	7.9	0.31	30	354	Old rubber trees fair, drainage bad; note increase in acidity below 12 ins. and free acid below 24 ins.
6	18	40	4.1	73	7.4	0.27	28	189	
12	29	39	3.6	114	6.7	0.22	26	255	
24	29	37	3.4	231	7.4	0.21			
36	37	43	2.9	2269	8.3	0.22			
3	10	50	4.6	65	10.5	0.29	103	396	Old rubber trees fairly good, drainage fair, "nutrients" high, slight increase in acidity at 36 ins.
6	10	41	4.4	47	5.8	0.14	34	322	
12	8	45	4.1	75	5.2	0.12	12	225	
24	6	41	3.8	82	4.6	0.12			
36	9	43	3.6	249	3.0	0.08			
3	16	31	6.7	317	3.2	0.15	292	859	Old rubber trees good, recently replanted, low stand owing to disease. Sea shells mixed with soil; note pH almost neutral and very high "nutrients." Drainage very good.
6	16	33	6.7	297	5.4	0.22	205	848	
12	17	31	6.7	150	4.0	0.15	129	482	
24	10	32	6.7	183	1.5	0.13			
36	21	23	7.3	174	0.9	0.03			
3	21	39	5.4	53	4.5	0.22	402	338	Area very close to above, old rubber trees very good, drainage good and "nutrients" high.
6	13	39	5.0	47	3.9	0.17	172	320	
12	8	41	4.4	60	2.7	0.13	35	247	
24	6	43	4.0	95	3.4	0.09			
36	6	44	3.5	189	3.8	0.10			
3	8		4.0	94	54.0	0.89	12	372	Shallow layer of peat over clay, poor bark in this area.
6	8		4.0	80	35.1	0.49	8	316	
12	24		3.8	98	13.0	0.19	6	222	
24	7		3.6	182	12.7	0.18			
36	6		2.9	710	9.9	0.18			

The height of the water table varies greatly and is the limiting growth factor in these soils. If drainage is good and the average yearly water table is below 42 inches, they are usually very fertile. On one Malayan estate, 1,400 acres of this type of soil have been replanted without the use of manures. The land was very well drained in advance of replanting, and creeping cover was used which has brought the top soil into excellent condition. Growth and general vigour of the trees are excellent.

On this estate there is a small area of very stiff clay soil where growth is very poor, manures are of no value but covers may after a time help to open the soil and improve growth. Extra draining of this soil does not help matters since water does not percolate through it.

In some coastal clays sea shells are mixed with the soil; an example is shown in Table V. The pH is about 7 and the plant food content is high; the soil is of good texture and well drained. It grows good rubber trees but not better than soils of pH 4.5.

Thin, loamy or peaty layers are sometimes found overlying clay, and these soils are usually good if the layer of peat is thin.

(2) PEAT

Areas of peat are found where the soil has been waterlogged for a considerable time. The peat usually overlies clay and its agricultural value is greater the thinner the peaty layer.

Little is known about the agricultural relationships of tropical peats. They must be drained, but when drained the crop may suffer from drought in dry weather.

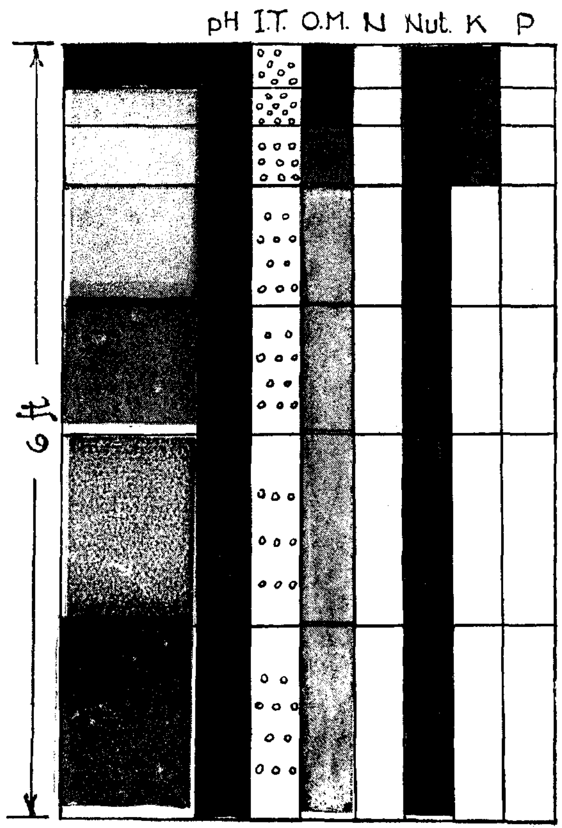
TABLE VI

Profiles on Peat

Lower depth inches	Sand per cent	I. T.	pH	Nutrients	O.M. per cent	N per cent	P_2O_5 p.p.m.	K_2O p.p.m.	Remarks
3			3.9	83	34.6	0.72	31	226	36 ins. of peat over clay, young rubber trees fairly good, probably needs potash and phosphate. Drainage good.
6			3.7	100	36.5	0 55	25	183	
12			3 6	157	46 2	0.57	23	161	
24			3.7	185	39.4	0.93			
36			3.6*	250*	75 0*	0.94*			
48			3.5	1240	9.9	0.10			
3			3.6	143	29 0	0 54	8	222	Old peat area. Badly drained, note acid soil. Old rubber trees poor. †Harmful amount of acid below 12 ins.
6			3.5	128	18.0	0.35	9	253	
12			3.5	207	16 0	0.35	9	309	
24			3.0	876†	16.0	0.32			
36			2.9	2615†	18.0	0.31			

*As the amount of soil available for analyses was too small these figures are calculated from data available.

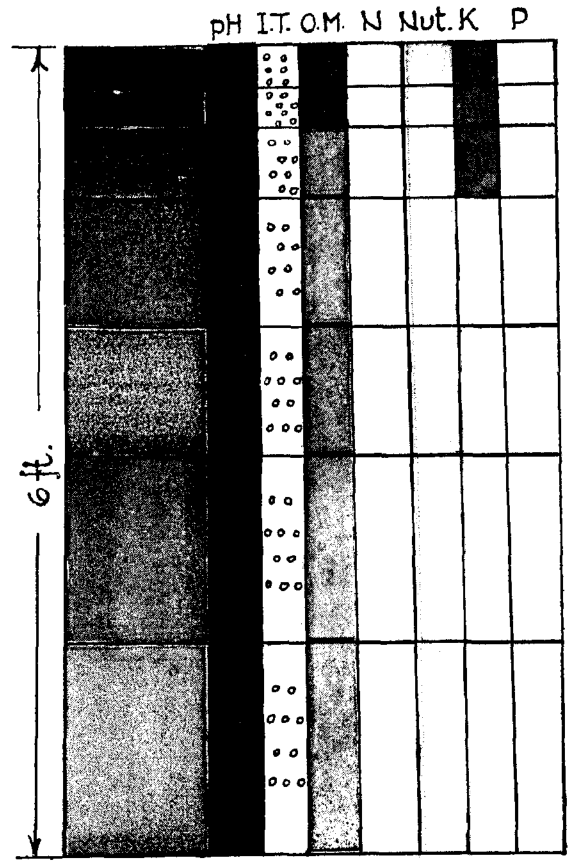
Fig. I.



Soil Type: Granite, sandy loam.

Remarks: Forest soil. Good texture. K and Nut high. N and O.M. high in topsoil. P low.

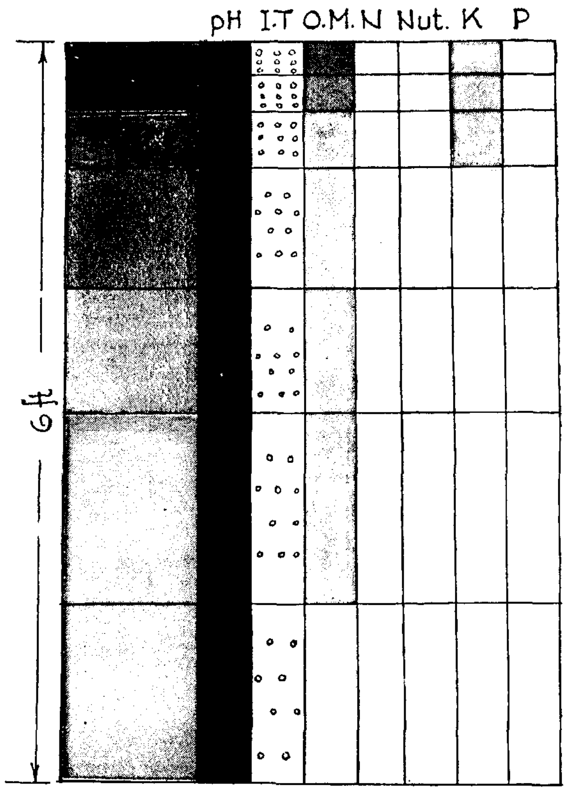
Fig. II.



Soil Type: Granite, sandy loam.

Remarks: Under Rubber 25 years. Good texture. N, P and Nut low. K fair. O.M. fair

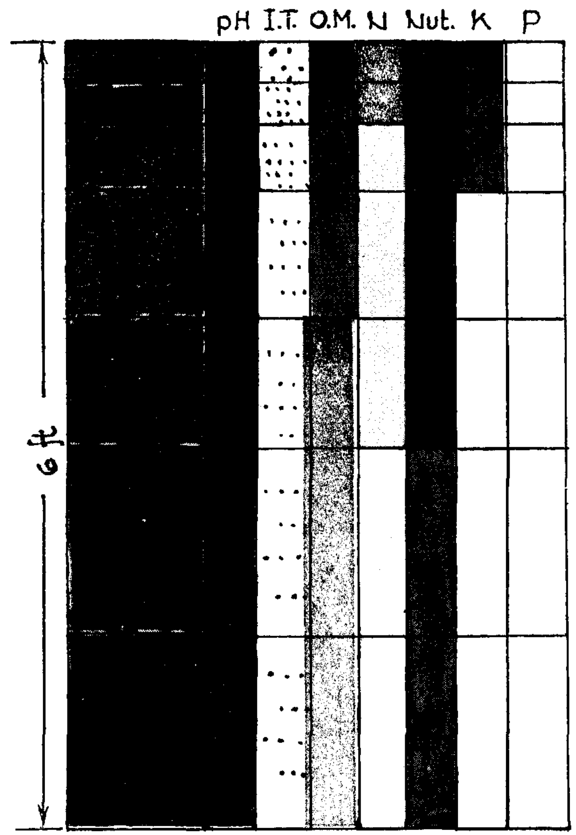
FIG. III.



SOIL TYPE: Quartzite, sandy loam.

REMARKS: Under rubber 25 years. Texture bad, excess sand. Plant food low.

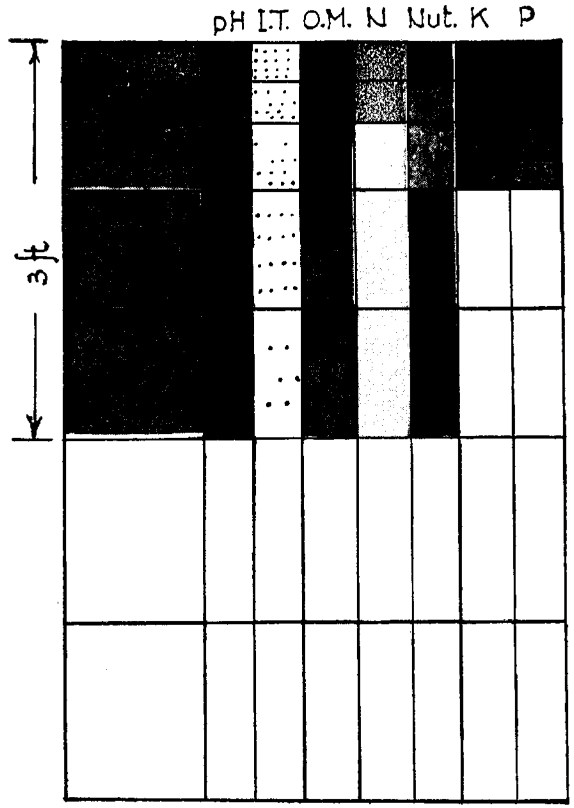
FIG. IV.



SOIL TYPE: Pahang Volcanic Series. Basalt clay loam.

REMARKS: Under rubber 27 years. Texture good. N. K. Nut and O.M. high. P low.

FIG. V.



SOIL TYPE: Coastal Clay.

REMARKS: Cultivated over 30 years. Well drained. Texture good. N, P, K, Nut and O.M. high.

A serious objection is the great shrinkage of peat after draining, rubber trees planted before much shrinkage has taken place are usually left with the majority of the roots above ground, and the chief problem on peat is to keep trees standing. Manuring with phosphate and potash is advisable on peaty soil. Nitrogen is not necessary, rubber leaves from peaty areas having very high nitrogen contents.

PROFILE CARDS.

The fertility attributes of some typical Malayan soil profiles are shown in Figs. 1—5.

The analytical values are represented as follows :—

Reaction (pH)
Dark blue ... ... Highly alkaline
Pink ... ... Neutral
Dark red ... ... Highly acidic

Index of Texture (I.T.)
Small number of circles ... Sand
Large number of circles
or small number of dots ... Loam
Large number of dots ... Clay

Organic Matter (O.M.)
Dark brown ... ... High O.M.
Light brown ... ... Low O.M.

Total Nitrogen (N)
Dark green ... ... High N
Light yellow ... ... Low N

" Nutrients " (Nut.)
Dark blue ... ... High Nut.
Light blue ... ... Low Nut.

Available Potash (K_2O)
Dark purple ... ... High K_2O
Light purple ... ... Low K_2O

Available Phosphate (P_2O_5)
Dark brown ... ... High P_2O_5
Light orange ... ... Low P_2O_5

Soil Analyses

Before concluding, a note on soil analyses is necessary.

Often soil samples are sent to the Institute from estates, with a request that these should be analysed, and as a result of analyses, that advice should be given on manures suitable for replanting or improving old rubber. It is impossible from soil samples sent in this manner to give any satisfactory advice. An inspection of the area is best, but if, as happens in many cases, that cannot be arranged at the time, some help can be given if the following information is given.

1. Position of area
2. Slope of land
3. Whether area was planted from jungle
4. Age of rubber trees
5. Any cultivation or manuring which has been carried out
6. Yields when the rubber trees were at their best and present yields (The tapping system should be given).
7. Condition of bark, foliage, etc.
8. Whether land is liable to water-logging
9. Any other relevant information.

In addition to this a few soil pits should be dug in different parts of the area and the following information given :—

1. Position of pit, *i.e.* top, bottom or side of hill
2. Colour of the soil profile exposed, any changes in colour with depth noted.
3. A rough idea of the soil texture, i.e. whether it is sandy, loamy or clayey.
   Compact laterite layers or loose laterite stones should be noted.
   Depth of water table, if visible.
4. Soil samples should be taken from one pit unless the area is very variable, when samples should be taken from each different type. The samples should be taken from the following layers 0-3 ins., 3-6 ins., 6-12 ins., 12-24 ins., 24-36 ins., 36-54 ins., and 54-60 ins.

A few, not more than six samples, should also be taken from the top six inches at various points in the area. All samples should be carefully labelled. This procedure will enable the soil type to be fixed and recommendations to be made accordingly.

In addition it will help in the survey of rubber soil types which, when taken in conjunction with field experiments, which are being laid down under the new experimental scheme on each soil type, will greatly advance our knowledge of the best treatment for rubber cultivation under various soil conditions.