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Soils of Malaysia

Coulter

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A Review of Investigations on their Fertility and Management

by

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SUMMARY

A reconnaissance soil survey has been done for the whole of West Malaysia and parts of East Malaysia. This has provided the framework into which more detailed soil surveys have been fitted and has stimulated work on such surveys for agronomic use. Using aerial photographs West Malaysia has been covered by a land use survey which has given the country an accurate inventory of the areas of important crops.

Research in Malaysia has shown that the fertility stored in forest soils, mostly in the organic matter, in areas of highly weathered and highly leached soils is extremely important for rubber and oil palm in the first planting cycle. The need for additional fertilizers in the subsequent planting cycles has been amply demonstrated. With fertilizers, dry matter production by permanent crops shows about the same efficiency of use of solar energy as that of annual crops in temperate areas though not as good as some forest crops in temperate areas. Well grown legumes can fix considerable quantities, of the order of 200 lb per acre per annum, of nitrogen. However growth is possible throughout most of the year in Malaysia so the efficiency of fixation appears to be about half that of temperate legumes which over a much shorter growing period fix around the same amount.

Compared with temperate soils many Malaysian soils can be described as 'fragile' and experience of fertilizer use on rubber and oil palm illustrates the great importance of the interactions of nutrients on poorly buffered soils. Thus magnesium is necessary where ammonium sulphate and potassium are being applied to such soils and may be more important than calcium for several crops

where other fertilizers are used intensively. Similarly trace elements normally are needed only when other fertilizers are being used. In the poorly buffered soils leaching is related to the type of anion in the fertilizers. Acidification by ammonium sulphate and loss of calcium are pronounced so the use of other fertilizers, for example, rock phosph that will supply calcium are important.

Crops in Malaysia appear to differ greatly in their tolerance of different levels of soil fertility. Tree crops like rubber and oil pa and also legumes can grow at phosphorus levels at which maize makes no growth. Phosphate retention varies much but laboratory measurements do always agree with field experience, for laboratory measurements of phosph retention may not indicate the residual values of phosphorus fertilizers.

Malaysia has considerable areas of peat and acid sulphate soils a the agronomic problems of the former and the chemistry of the latter req much investigation. Investigations already done indicate that with pr management, especially of the water table regime, they can be made produ

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SOILS OF MALAYSIA

A Review of Investigations on their Fertility and Management

1. INTRODUCTION

1.1 The term Malaysia covers the three territories formerly referred to as Malaya, North Borneo (Sabah) and Sarawak. Malaysia has a total area of 128,338 sq.ml. (332,395 sq.km.) and the population, which is increasing at about 3 per cent per annum is approximately 10,000,000 (1970).

1.2 The climate is equatorial with rain from both the north east and south west monsoons, the lowest annual rainfall being about 70 in. and the highest exceeding 200 in. Only in the extreme north is there a well marked dry season and even there evaporation only exceeds rainfall for about 3 months each year. With a mean temperature of approximately 80°F (27°C) the country is therefore typical of the humid tropics being both hot and wet throughout the year.

1.3 The major food crop of the region is padi rice; only in Sarawak and to some extent in Sabah is dry land rice important. About 1 million acres of rice is grown and some 10 per cent of the area is double cropped, the new high yielding varieties being popular for the off season crop. It should be emphasized that there is little continuous arable dry land cropping; vegetables are cultivated by Chinese farmers using large quantities of organic manures and some tapioca is grown, as a cash crop and for pig food, but the areas are not extensive. Maize, except under specialised conditions on the richest soils, usually gives low yields. Thus Malaysia can offer few examples of continuous cropping and sustained yields from arable dryland crops.

1.4 The major cash crops are rubber, grown on estates small holdings, oil palms and coconuts with pineapples and of less importance. Rubber has been grown since early thi century but oil palms only assumed importance in the 1920' For both crops varietal improvement and fertilizer use has enhanced yields enormously. The old seedling rubber produ under average management on estates, about 300 to 400 lb/a annum. New varieties are capable of exceeding 2000 lb/acr annum and many large estates now average well over 1000 lb acre/annum. The first oil palm plantings yielded about ha a ton of oil/acre/annum, but the new hybrid material now p yields of the order of 2 tons of oil/acre/annum under comm conditions. Full exploitation of the yield potential of r and oil palms by improving soil fertility has been an outs feature of Malaysian agricultural development.

1.5 Pineapples were initially grown as a catch crop wh establishing rubber plantations but soil erosion was so se that catch cropping ceased and the commercial crop, for ca is now grown almost entirely on peat soils. The 40,000 to 50,000 acres used for this crop constitute one of the few of successful large scale exploitation of acid tropical pe Yields are, however, very low, averaging about 3 to 5 tons fruit/acre/annum compared with yields of 15 to 20 tons on commercial plantations elsewhere. Cocoa has made disappoi progress and yields have been mediocre except on the best volcanic soils in Sabah. Coconuts are widely grown, espec by small holders, but their yields of oil cannot match the oil palms, and estate production is declining.

1.6 Because of the well distributed rainfall, dry matter production in Malaysia can be high. Thus Gray (1969) reported 30,000 lb/acre/annum of dry matter production by oil palms, corresponding to a conversion of 0.9 per cent of the average solar radiation of 420 calories/cm^2/day. A comparable value for rubber given by Templeton (1968) is 31,600 lb/acre/annum. Ure and Jamil (1957) give 43 tons/acre of green matter from Napier grass with an application of 20 cwt. of sulphate of ammonia. At 20 per cent dry matter this is equivalent to 19,000 lb/acre/annum, considerably less than the 1 per cent efficiency of solar radiation conversion suggested by Penman (1969) as representative of the best farming in Europe.

2. SOIL TYPES

2.1 General Description

2.1.1 Investigations on soils have been going on for about 50 years though the number of soil scientists working in Malaysia at any one time scarcely exceeded half a dozen until about 1947. Thereafter research staff in Government, commodity and commercial organisations increased considerably and there has been a corresponding increase in the information about the major soil types and their cropping potential.

2.1.2 In an initial break-down the soils of Malaysia can be divided into two broad groups, the sedentary soils formed in the interior on rocks with a wide range in composition, and the soils of the coastal alluvial plains, which, in Malaya, may extend 40 miles inland. The interiors of Malaya, Sabah and Sarawak are mountainous and the rivers have relatively short courses; thus the alluvium along the rivers is not extensive compared with the alluvium of the coastal plains, much of the latter of marine origin.

2.1.3 There are four main types of soils in the coastal plain

(i) the rich clay and clay loam soils covering large areas on the west coast of Malaya and small area in Sarawak and of great importance agriculturall

(ii) the deep forest peats which cover an estimated 2 million acres in Malaya and 3.6 million acres in Sarawak, (Anderson 1964);

(iii) the acid sulphate soils scattered throughout the coastal plains of all three territories covering perhaps ¼ million acres;

(iv) the sandy soils of the old raised beaches of the east coast of Malaya and parts of Sabah and Saraw

2.1.4 The sedentary soils are developed on igneous, sedimenta and metamorphic rocks, the latter two being mostly of Triassic and Carboniferous age. These soils, regardless of type of pare material are, except on unstable sites, deeply weathered and have few reserves of weatherable minerals. Their clay minerals are mostly kaolinitic though some of those derived from shale have vermiculite and illite. Table 1, taken from Ng (1965) shows their similarity in chemical composition.

Table I

Exchangeable calcium and potassium (in. me/100g) in some Malaysian Soils

Soil Series	Parent Material	0-3 in.		3-12 in.		Depth 12-24 in,		24-36 in.		36-48	
		K	Ca	K	Ca	K	Ca	K	Ca	K	
Rengam	Medium granite	0.33	0.08	0.25	-	0.12	<0.02	0.10	-	0.09	<
Jerangau	Fine granite	0.17	0.12	0.07	-	0.06	<0.02	0.06	-	0.06	<
Kuantan	Basalt	0.29	0.42	0.08	-	0.06	<0.02	0.06	-	0.06	<
Kala	Granite*	0.38	1.27	0.33	-	0.72	0.01	1.28	-	1.05	
Serdang	Sandstone	0.19	0.55	0.13	-	0.09	0.02	0.08	-	0.08	<
Munchong	Shale	0.24	0.04	0.10	-	0.08	<0.02	0.08	-	0.07	<
Selangor	Marine Alluvium	0.99	6.90	0.80	-	0.62	5.20	0.68	-	1.34	1

* Kala series is on an unstable site with continuous rejuvenation.

2.1.5. Further details taken from Mohinder Singh and Talibudeen (1969) are given in Table II.

Table II

Chemical and Physical Characteristics of 0-6 in. horizons of some important soils of Malaysia.

Soil Series	% Clay	Surface area (m^2/g)*	pH ($CaCl_2$)	Ex.Al** (me/100 g Soil)	Total Ex. Cations (me/100 g Soil)	% Al Saturation
Rengam	41	111	4.0	1.92	2.93	65.5
Serdang	26	68	3.8	5.08	5.89	86.2
Selangor	40	188	3.6	12.40	15.96	77.7
Kuantan***	46	248	4.3	0.90	2.63	34.2
Segamat***	57	149	4.3	0.70	2.05	34.1
Batu Anam	51	66	3.8	3.10	4.75	65.3
Chemor	15	44	4.2	1.33	2.25	59.1
Ulu Tiram	20	62	4.2	1.60	2.51	63.7

* By ethylene glycol adsorption

** N NH_4Cl

*** Mohinder Singh and Ratnasingham (1968) suggest that these are the only soils with significant amounts of exchangeable hydrogen+

Though these tables indicate that chemical characteristics of the inland soils are similar except for percentage aluminium+++ saturation in the Kuantan and Segamat Series, the physical conditions, particularly structure and texture, are very different. Because such differences can be identified in the field, parent material forms the basis for distinction between different soil series.

2.2. Classification and Mapping

2.2.1. Some early work on the description and classification of Malayan soils was done by Dennett (1929, 1932, 1933), Savage and Wilshaw (1932) and Hamilton (1936). Because of the obvious influence of parent material on soil profile characteristics and the availability of geological maps where no soil maps existed, the early classifications used geology as a major distinguishing feature. A later classification by Owen (1951) was also based on the geology, but he was able to include more information from the geology and also on the performance of the soils, particularly for rubber. He identified and described seventeen soil series and classified them as reddish brown latosols, yellow latosols, yellow podzolic and ground water laterite in the classification of Kellogg and Davol (1949).

2.2.2. In 1957 a schematic reconnaissance soil survey of Malaya was undertaken and as more information on the nature and distribution of the soils accumulated, Panton (1964) classified the series, which had then been mapped, into Great Soil Groups. Leamy (1966) classified the soils according to the 7th Approximation of the USDA, as did Allbrook (1968) in the more recent edition. The schematic reconnaissance soil survey of the whole of Malaya has now been completed and about 100 soil series have been identified and described (Leamy and Panton 1966); they have been mapped in associations at a scale of 1:500,000 (Law and Selvadurai 1968). A map at the same scale has also been published for Sarawak, (Soil Survey Staff, Kuching 1966). Twelve Great Soil Groups are shown on this and these have been placed within equivalent groups of the first draft of the World Soil Resources Report of F.A.O; several families are described within each Great Soil Group. The reconnaissance soil survey of Sabah is not yet complete but will be completed by 1973 (Thomas priv. comm.)

2.2.3. Apart from reconnaissance mapping, considerable areas have been mapped in more detail, generally at 1:50,000. These surveys were undertaken in new areas for rice irrigation or new settlement in Government sponsored projects. In addition Guha (1968) started to map the soils of all the rubber growing areas at a scale of 1:12,500; in three years about 1 million of the 4 million acres of rubber land have been mapped. In this survey samples are taken from one profile pit for every 100 acres, thus giving 40,000 profiles for the 4,000,000 acres to be mapped; soil boundaries at the series level are determined by augering.

2.2.4. In conclusion it can be said that Malaysia has as much knowledge of the distribution and morphological and chemical characteristics of its major soils as any country in the tropics, and probably more than most. The major gap appears to be a lack of information on how to manage the inland soils for crops other than rubber and oil palm.

2.3. Use of Soil Maps

2.3.1 Because of a forward looking policy, including the establishment of an Economic Planning Unit which made full use of natural resources information, soil maps have played a major part in planning agricultural development (Lee 1968). By combining information on mineral and soil and forest resources, Land Capability Maps have been produced and used to select areas for large scale development schemes.

2.3.2. A survey of present land use, using 1:25,000 aerial photographs and separating out about 30 categories of land use (Donaldson 1968), has also been done. This has proved valuable in obtaining accurate acreages of various crops (otherwise under-estimated on occasions by a considerable percentage) and of correlating land use with soil type. Information of this type is obviously invaluable in a country's development plans, though it is easier to do such a project in Malaya than in Africa or Latin America. In Malaya virtually the whole of the agriculture is permanent cultivation - even padi occupies the same land year after year - so that it does not matter at what season aerial photographs are taken. In Africa and Latin America, where there is much shifting cultivation, the type and acreage of crops shown on the photographs depend on the time at which they were taken.

3. SOIL FERTILITY

3.1 Introduction

3.1.1 Investigations on soil management can be conveniently divided into three major areas, fertility experiments using field and pot trials, examination of the nutrient status of the soils by chemical analysis and investigations on nutrition status of plants using material from field, sand and water culture experiments.

3.1.2 By far the greatest proportion of the field experiments has been done on rice, rubber and oil palms. Experiments on rice started many years ago, first on experiment stations and later (about 1950) extended to farmers' fields. Experiments on rubber and oil palms and to a lesser extent on coconuts were done on estates as well as on research stations. On tree crops Malaysia has probably had more fertilizer experiments over a greater area than anywhere else in the tropics. The magnitude of the programme may be judged from the fact that for oil palm, one factorial experiment with four fertilizers at three levels covers about 30 acres; one estate group may run between five and ten of these simultaneously. The Rubber Research Institute has about 30 long term fertilizer trials, each trial occupying on average 10 to 15 acres. To cover the major soil types, most of the fertilizer trials have had to be done on commercial estates, long term trials are possible on these because the standard of management is high. As well as recording yields, many of the experiments on oil palm and rubber have had annual leaf analysis and measurements of growth parameters.

3.2. Manurial Trials on Rubber

3.2.1 The amount of nutrients removed by 1300 lb/acre/annum of dry rubber is given by DeGeus (1967) as 8.4 lb of nitrogen, 1.7 lb of phosphorus and 5.8 lb of potassium. By contrast the amounts of nutrient stored in the timber (trunk and branches) of one acre of 33 year old rubber trees is given by Shorrocks (1965) as 1240 lb of nitrogen, 195 lb of phosphorus, 880 lb of potassium and 290 lb of magnesium. This indicates that once the nutrients for tree growth have been supplied the levels required for latex production i.e., the amount of nutrients actually removed from the field, are small.

3.2.2. Bolton (1964), when reviewing the progress of manurial experiments, divided the economic cycle of the rubber tree into two phases, the immature period from the time of planting the root stocks to the time of tapping, when fertilizer effects are measured by girth increment, and the mature period when the trees are tapped. In the early experiments on immature trees planted on land cleared from virgin jungle, a combination of nitrogen and phosphorus gave better growth on most inland soils but had no effect on the coastal alluvial soils. Later experiments, on rubber replanted on old rubber land, showed that nitrogen and phosphorus fertilizers were essential for satisfactory growth on the inland soils though they had only a small influence on the coastal alluvial soils. Responses to potassium depended on soil type; growth was often depressed on the coastal clays and heavy inland soils, particularly in the absence of nitrogen fertilizers, but on the more sandy soils there was improved growth.

3.2.3. With an increased tempo of replanting, a marginal chlorosis of the leaves of both immature and mature areas became more noticeable and this has been identified as magnesium deficiency; Bolton and Shorrocks (1961) reported highly significant girth increment and yield responses using $1\frac{1}{2}$ and 3 lb of magnesium limestone per tree. It is thought that some of the growth depression given by potassium fertilizers in the earlier experiments was due to enhancement of magnesium deficiency and that the more frequent appearance of magnesium deficiency symptoms is due to increased use of sulphate of ammonia. Fertilizers, particularly for sandy inland soils now generally contain magnesium (kierserite).

3.2.4. Fertilizer experiments on mature rubber were started many years ago, but one of the difficulties with mature trees is the slow response to fertilizers for, due to the relationship of yield to girth, it may be several years before increases in yield are noted. Furthermore increases in yield have to be of the order of 10 per cent to be statistically significant but a yield increase of 5 per cent is often of economic significance. The problem of detecting economically significant as opposed to statistically significant yield increases is one confronting experimenters with oil palms and other tree crops, as well.

Bolton (1964) states that because of the lack of any clearly defined needs except for nitrogen emerging from the earlier experiments on mature trees, the most usual practice has been the application of 2 cwt/acre of a mixed fertilizer up to 10 years before replanting; magnesium deficiency is corrected as it appears by the use of dolomitic limestone.

3.2.5. Further information, relating fertilizer responses to soil type, is now becoming available and attempts to give more discriminating advice on fertilizer use are now being made. Thus the results of Pushparajah (1969) with potassium and with phosphorus, potassium and manganese factorial experiments on Rengam series soil (a soil derived from medium grained granite) indicate the importance of soil type. The nitrogen, phosphorus and potassium experiment was planted in 1949 and the phosphorus, potassium and manganese in 1959 and both were given the standard treatment for immature rubber trees. Experimental treatments were applied from 1957 to 1963 in the former and from 1962 until 1966 in the latter. Potassium had a beneficial effect on girth increment and yield; nitrogen alone depressed growth increment and yield but the combination of nitrogen and potassium at the highest levels (6 lb sulphate of ammonia and 1½ lb muriate of potash per tree) increased yield in one of the experiments by 900 lb/acre/annum, a 36 per cent increase. Manganese significantly increased girth but not yield. As adequate phosphorus had been applied during immaturity its application did not increase yield.

3.2.6. Guha (1969) has also attempted to refine current fertilizer advice by mapping soil series, determining the variation of several nutrient levels within the series and measuring leaf nutrient levels. The soils of estates have been mapped and soil and leaf samples collected from representative sites. The analytical data have then been interpreted to assess fertilizer requirements, taking into account the relative field conditions, the performance and age of the trees, past fertilizer applications, susceptibility to wind damage, ground cover and other management factors.

3.2.7 An interesting fact emerging from the fertilizer work on rubber has been the enhanced needfor fertilizers on areas replanted from old rubber. Some of this may arise from the greater demand made on the trees by high yields, but the greater part is probably due to the loss of fertility, initially by the clean weeding programme in the early stages of the industry and then the subsequent loss of the accumulated nutrients in the trees by clearing and burning.

3.2.8. Types of Fertilizers The normal constituents of the fertilizers used for rubber are ammonium sulphate, Christmas Island rock phosphate (36% P_2O_5) and muriate of potash. Some trials have compared the value of sulphate of ammonia with sodium nitrate or urea and Christmas Island rock phosphate with superphosphate. Trials have also compared application of phosphate by broadcasting, by placing in holes or by ploughing into the soil. Generally the trials with phosphate have indicated that in the very acid soils of Malaya, rock phosphate is as good as the water soluble phosphates (RRI 1955) and on occasions better (RRI 1961); however in one experiment fused magnesium phosphate was reported to be superior to rock phosphate (RRI 1964). Placement in the planting hole or in the top 6 to 18 in. of soil had no advantage over broadcasting but ploughing in 4½ or

9 cwt/acre improved the rate of establishment of cover crops (RRI 1965), and granular compounds of fertilizer were not superior to established mixtures (RRI 1966).

3.2.9 Middleton (1960) compared rock phosphate and triple super-phosphate as sources of phosphorus for seedling rubber in large pots; the phosphate was broadcast on the surface or uniformly mixed with the top 4 in of soil or pocketed in 8 symmetrically arranged positions around the plant in the pot. In addition each treatment was repeated using soil in which the original pH of about 4.5 had been adjusted by liming to pH 6. Basal treatments of nitrogen, potassium and manganese were given as well as trace elements. There was a well marked response to rock phosphate in the absence of lime and the response was greatest for the broadcast method and least for the pocketing method. When lime was added response to rock phosphate was almost completely suppressed for all methods of application; lime on its own had a small positive effect on growth. The effect of lime was attributed to the increased pH depressing the solubility of the rock phosphate. The response to super-phosphate was generally no greater than to rock phosphate but the order of efficiency of the different methods of application was reversed, i.e. pocketing was the best and broadcasting the worst with mixing intermediate. The effect of lime also differed for there was only a slight suppression of response to superphosphate in the presence of lime. Calculations showed that the plants took up only 0.3 to 4 per cent of the phosphorus in rock phosphate compared to 2.3 to 7.0 per cent in the superphosphate. Though only a small proportion of the added phosphorus was utilized by the plants some of them were showing phosphorus deficiency symptoms at the end of the experiment and the author concluded that over 90 per cent of the phosphate was fixed by the soil in a form not readily available to the plant, a conclusion similar to that of Owen (1947).

3.2.10 Middleton and Pushparajah (1966) in summarizing the investigations on forms of phosphate for rubber state that field trials comparing rock phosphate with soluble phosphate had generally shown Christmas Island rock phosphate to be as efficient as the soluble phosphates, even when compared on the basis of P_2O_5 applied. Experiments had also shown rock phosphate to be particularly effective in the presence of ammonium sulphate and magnesium sulphate as it had a supplementary value increasing available calcium and decreasing acidity in the soil. As rock phosphate is only about half the price, per unit P_2O_5, of superphosphate, the former is used almost exclusively in fertilizer mixtures for rubber. Between 1954 and 1964 imports of rock phosphate into Malaya increased from about 5000 to 35,000 tons per annum, almost all for rubber; the import of processed phosphates remained virtually static during the same period.

3.2.11 Forms of nitrogen fertilizer have been compared in field experiments; on a poor sandy soil "Nitrochalk" was less effective than sulphate of ammonia as a source of nitrogen (RRI 1963), and urea was not superior to sulphate of ammonia (RRI 1966). Sulphate of ammonia and ammonium nitrate were equally effective and better than calcium nitrate and ammonium chloride. Investigations on volatilization of ammonia (4.6) revealed that under appropriate conditions (applying urea on covers or to soils with moderate moisture content) losses of ammonia could exceed 20 per cent.

3.3 Manurial Trials on Oil Palm

3.3.1 Unlike rubber a large amount of nutrient is removed in the fruit of the oil palm and, in addition, considerable quantities are stored in the trunk, roots and fronds, though regular pruning of the fronds eventually returns their nutrients to the soil. Ng and Thamboo (1967) give the amount of nutrients removed in 10 tons of fresh fruit bunches per acre (Table III).

Table III

Nutrients in 10 tons of Fresh Fruit Bunches (lb/acre)

Nutrient	Amount
Nitrogen	64.9
Phosphorus	9.7
Potassium	81.8
Magnesium	17.9
Calcium	16.9

By measuring the dry matter production and nutrient content of palms of different ages, Ng et al (1968) calculated the annual uptake of nutrients for vegetative growth and reproduction of adult palms (Table IV)

Table IV

Annual uptake of nutrients in Oil Palms (lb/acre)

Nutrient	Amount
Nitrogen	172
Phosphorus	23
Potassium	224
Magnesium	55
Calcium	80

3.3.2 Against this uptake may be set the nutrients returned eventually to the soil in the pruned fronds which for potassium amounts to 77 lb/acre/annum. These values indicate the drain on soil nutrients, particularly potassium, and it is of interest to compare the amount of potassium stored in an acre of palms with that in the soil. Using Ng's (1965) tables for exchangeable potassium in 0-3 ft of Rengam series, a soil widely used for oil palm, the total exchangeable potassium is about 860 lb/acre, i.e. about 4 years' supply for adult palms.

3.3.3 Fertilizer trials were started many years ago by the Malayan Department of Agriculture (Belgrave 1932, 1935, Belgrave and Lambourne 1933, 1937, Bunting 1932, Bunting, Georgie and Milsum 1934, Dennett 1938, Guest 1937, Wilshaw 1940 and Hartley 1950) and the results of these have been summarized by May (1956). These early experiments tested nitrogen, phosphorus, potassium and magnesium fertilizers in various combinations. However, the treatments were not consistent over the years for changes were made in the type of fertilizer applied. All these early experiments were on inland soils; in none was there a response to nitrogen fertilizer alone, though some of the results suggested that nitrogen plus phosphorus was beneficial. The reason for a lack of response may be that most of the experiments were done on areas planted on cleared jungle land. The experiments showed that phosphorus, either alone or in mixtures with nitrogen or potassium, was necessary to increase or even maintain the yields of mature palms and phosphorus fertilizers increased the weight of fresh fruit bunches by 30 to 70 per cent. Application of rock phosphate, exceeding

4 lb per palm per annum, produced no further increases and basic slag had about the same effect as rock phosphate.

3.3.4 In spite of the low potassium levels in the soils and the oil palms' need for large quantities of potassium only one experiment showed a significant yield response to potassium and that to a mixture of potassium and magnesium (Hartley 1950). The lack of response to potassium in these early experiments may have been due to genetically low yielding material, to potassium reserves from the jungle clearing, to the use of only small amounts of sulphate of ammonia or to low levels of magnesium in the soil.

3.3.5 In the 1950's many more experiments, almost all of factorial design, were laid down by two large companies, one operating mostly on the inland soils the other on the coastal soils, but only a limited amount of information has been published about these experiments. Rosenquist (1962) describes experiments started on inland soils (laid down in 1949) in which the treatments were 0, 2 and 4 lb of sulphate of ammonia, 0, 3 and 6 lb of Christmas Island rock phosphate, 0, 2 and 4 lb of muriate of potash and 0 and 2 lb of kieserite per palm per annum. There were differences depending on soil type, a granite soil showing a highly significant (33 per cent) yield response to potassium, and a smaller one to nitrogen. On an old terrace soil the response to phosphorus was 22 per cent and to nitrogen, 11.6 per cent. The responses to potassium were linear, suggesting further increases at high levels; in the presence of potassium, magnesium achieved significance at some sites. Since Rosenquist's report later experiments confirm that higher dressings of potassium are needed to exploit and maintain the high yield potential of the new varieties. Thus Turner and Bull (1967) suggest that on inland soils planted from newly cleared jungle 6 to 8 lb per palm of muriate of potash may be needed to maintain a high level of yield: on areas replanted from a previous oil palm stand as much as 10 to 15 lb/palm/annum may be required for sustained high yield. This is equivalent to an annual dressing of 500 to 650 lb/acre of muriate of potash. Turner and Bull also point out that dressings at this level may upset the magnesium and boron balance of these soils and these must be catered for in the fertilizer programme.

3.3.6 The young alluvial soils of the coastal areas have much higher reserves of nutrients, particularly potassium, so responses to potassium fertilizer have been small. However, whilst excellent yields can be maintained without fertilizer there are indications that, for sustained high yields, some fertilizer will be necessary. This is likely to become more essential where areas have been replanted by palms following palms. Nevertheless within the broad type, alluvial soils, differences in fertilizer response have been demonstrated and there have been considerable responses to nitrogen in the growth and time to maturity of young palms on soils derived from river alluvium.

3.3.7 Peats and acid sulphate soils are scattered amongst the coastal alluvial soils and areas of these have been planted up with oil palm, either inadvertently or to round off estate boundaries. Yields on the acid sulphate soils have been particularly poor (Bloomfield and Coulter 1968). Some yield responses have been obtained from nitrogen, phosphorus and magnesium fertilizers but any substantial improvement depends on raising the water table so that the potential acid sulphate forming horizons are kept waterlogged; by doing so yields have improved from 2 to 3 tons to 7 tons/acre (fresh fruit bunches). On peat soils potassium is very necessary and copper also appears to be needed; the latter is discussed in the section on trace elements. In experiments on these soils, leaf analysis has demonstrated an antagonism between magnesium and copper with many of the palms being extremely low in copper and very high in magnesium.

3.3.8 Fertilizer experiments and commercial experience have demonstrated that, under the high and well distributed rainfall of Malaya, extremely good yields from oil palms can be obtained, even on soils very poor in nutrients. Like the experiments on rubber, they indicate that the initial reserves of nutrients, after clearing from jungle, are of great advantage to the first planting cycle but that the second cycle needs heavy fertilizer, in this case potassium which is removed in such large quantities. Thus an annual yield of 10 tons fresh fruit bunches/acre for a 25 year cropping cycle depletes the soils' reserves of about 1600 lb of potassium per acre. In addition to that removed, a considerable quantity is immobilized in the vegetative growth of the palm; taking this into account and assuming that all potassium in the fronds is returned to the soil, the nett removal is about 140 lb/acre/annum, virtually the same as that given by Cooke (1967) for sugar beet. However, the latter is grown only once every few years, often on soils with considerable reserves of total potassium, whereas oil palms require this amount annually, sometimes on soils with total potassium levels of the order of 0.2 per cent.

3.4 Manurial Trials on Padi

3.4.1 Padi rice is the second most important crop in Malaysia, nearly a million acres being grown. As it is the staple food the Department of Agriculture has long been concerned with improving yields, and fertilizer trials were started many years ago. These early trials showed no response to nitrogen, but a response to phosphorus, more particularly on the sandier river alluvial soils of the east coast (Kelantan) where the yield increases were of the order of 30 per cent; these trials also gave rise to the idea that a "bar" existed at about 3000 lb/acre, beyond which it was not possible to increase yields by any known fertilizer technique (Belgrave 1937). The "bar" was all the more mystifying as areas were known which consistently gave yields of 4,500 lb/acre or more, without fertilizer, which indicated that neither varietal nor ecological factors were responsible. Even in pot experiments the soils from the better yielding areas gave higher yields than those from the lower yielding areas though fertilizers were given to the soils of the latter.

3.4.2 The fertilizer programme used many different types of fertilizers in large amounts to increase yields. Thus Wilshaw (1937) describes an experiment in which 22 cwt/acre of ground horn (12 per cent nitrogen), which had given promising results in pot experiments and 48 cwt/acre of rock phosphate were used.

In addition various forms of cultivation and different plant spacings were tried. Once again responses only to phosphorus were obtained in soils known to be deficient in phosphorus. Heavy dressings of sulphate of ammonia (1500 lb/acre) split for application at various times gave no yield increases. Wilshaw summarized the results of 27 such experiments by saying that phosphorus gave a small increase in yield but in very few cases was this economic. In 1939 he also summarized the results over 9 years, in which a large number of field and pot trials were done, by stating that the amount of positive information gained was small, the amount of negative information great; he concluded that the padi soils in the western areas of Malaya (the major padi growing areas) were only slightly responsive to fertilizers. Birkinshaw (1940) reviewed all the work done to that date on fertilizers, green manures and various forms of cultivation; he came to the same conclusion as Wilshaw, the only new information being that off-season cultivation of vegetables at one station gave increased yields of padi in the subsequent season even when no fertilizer had been used.

3.4.3 Fertilizer trials were resumed after the Japanese occupation and since the earlier trials had suggested that phosphorus responses were the most likely, attention was concentrated on different forms and rates of phosphorus. Thus in one trial, Allen (1951) found that 300 lb/acre of ammonium phosphate placed below the plants at 6 or 10 weeks after transplanting increased yields by about 50 per cent, from 2,200 to 3,400 lb of padi per acre. Off-season cropping and off-season manuring and various forms of cultivation, deep ploughing, shallow ploughing and late and early ploughing were all investigated in experiments. The only interesting factor emerging from the cultivation trials was that the cultivators' own technique of shallow, late ploughing gave the best weed control (Allen 1951).

3.4.4 The general lack of substantial fertilizer response led to more field trials being done and over a 100 were laid down in 1951 (Allen 1952). The major result from these was that ammonium phosphate gave the most consistent increases in yield, and it was concluded that Christmas Island rock phosphate was not a suitable fertilizer for padi throughout Malaya; some responses to potassium on sandy soils were reported, and no residual effects from ammonium phosphate were found. The trials did show that the right fertilizer applied at the right time gave economic returns in many areas. Where significant responses were obtained they seldom exceeded 50 per cent even on the poorest soils and the best yields were usually about 3000 lb/acre or less. On the better soils yields of over 4,000 lb/acre were obtained in the control plots.

3.4.5 More detailed comparisons of ammonium phosphate and other phosphatic fertilizers were done in a later series of experiments by Allen and Henderson (1956); they showed that a mixture of sulphate of ammonia and triple super was as good as ammonium phosphate, but as a result of this series they also revised ideas on the insoluble phosphates and suggested that there was little to choose between the efficiency of the two forms, though 50 lb P_2O_5 as triple superphosphate was at least as efficient as 100 lb P_2O_5 in the water insoluble form;

consequently they suggested that Christmas Island rock phosphate would be suitable as a padi fertilizer. The reasons for revising ideas on water soluble versus insoluble phosphate fertilizers are not clear but this comprehensive series of 220 replicated experiments and 380 experiments on small holders' land confirmed the value of the insoluble phosphates. The series also showed that manuring the padi nurseries with ammonium phosphate was highly beneficial and gave very good economic returns.

3.4.6 Other facts to emerge from this series included the magnitude of the response to fertilizers where yields were already high. Percentage wise the responses were sometimes as good as those on poor soils and in terms of total yield considerably better. They also showed that fertilizers could not raise the levels of yields in the poorer areas to those of good areas. They confirmed that other factors, including water control, often limited yields.

3.4.7 Until about 1960 all the fertilizer experiments were done on long strawed <u>indica</u> varieties which are known to be less responsive to nitrogen and to lodge readily. Varietal x fertilizer trials indicated little difference in varietal response, probably because the original selections had been made in the absence of fertilizers. Although <u>indica</u> varieties are less responsive to fertilizers it is incorrect to conclude from those trials that high yields cannot be got from such varieties, although this is often given as a reason for growing <u>indica</u> x <u>japonica</u> hybrids. The yielding ability of the <u>indicas</u> under conditions of high fertility is shown by Allen (1957) for areas in Salangor where, on several thousand acres, the average yield was 5,500 lb/acre with individual farmers getting over 7,000 lb/acre (Ng and Indot 1957). Recently the indica x japonica hybrids have been used in trials and their responses to 40 and 80 lb of nitrogen per acre is given by Van (1966); he gives mean yields approaching 4,000 lb/acre: and quotes responses of the order of 500 lb/acre from 40 lb of nitrogen with no yield increases for nitrogen above this.

3.4.8 Most of the padi experiments have been done in Malaya, but there have been a few trials in Sabah and Sarawak. In Sarawak, Dunsmore (1968) reports the results of nitrogen, phosphorus, potassium factorial experiments on research stations and simple trials done on smallholders' land. In areas where cultivation is satisfactory there have been responses; in 25 experiments harvested in the seasons 1965, 1966 and 1967 the mean response to 20 lb of nitrogen and 12 lb of phosphorus per acre was 333 lb of padi with a range from 29 to 885 lb; 130 lb of padi would cover the cost of this fertilizer. In later experiments higher dressings, 40 lb/acre of nitrogen and 24 lb/acre of phosphorus, gave bigger responses. There were normally no significant differences between nitrogen supplied as urea and as sulphate of ammonia; Christmas Island rock phosphate and superphosphate gave similar responses, the former being much cheaper. The most recent experiments suggest that top dressing with 50 lb/acre of urea 3 weeks after transplanting is beneficial. There have normally been no responses to potassium.

3.4.9 As the major rice growing areas are on the coastal alluvium soils, they include some areas of forest peat and sometimes these form part of an irrigation scheme. Generally, poor crops of padi grow on peat and a number of fertilizer experiments have been reported by Allen and Coulter (1957). On a deep peat of pH 4.1, padi responded to burning the surface layer and to application of superphosphate. One ton/acre ground magnesium limestone, sodium nitrate and muriate of potash gave no responses. Yields of straw were about 6,000 lb/acre and there was a marked residual effect of phosphorus. In a trace element experiment copper, zinc, molybdenum, boron and manganese were sprayed on 7 weeks after transplanting; copper caused severe scorch and depressed yields, but there was some suggestion that the other trace elements might enhance yields.

3.4.10 In addition to trials with the usual fertilizers some experiments have been done with silica. Miyake (1964) using furnace slag found increased silica levels in the straw but no yield responses. Other experiments appeared to show beneficial effects of silica on yield, but only of the order of 10 per cent; on the other hand high rates of furnace slag appeared to depress yields, so no clear picture of the need for silica by rice has emerged from these trials.

3.5 Manurial Trials on Other Crops

3.5.1 Pepper Sarawak is a major pepper producer and the crop used to be grown under a system of shifting cultivation with new gardens being opened up in jungle every 10 to 15 years, the usual size of the garden being about 1 acre; to build up the fertility of this area an additional 4 acres of jungle was used to supply top soil and timber for preparing burnt earth (de Waard 1969). In the last couple of decades land use has been restricted, the cultivators have had to replant the same areas and the preparation of burnt earth has been prohibited by the Government. Heavy dressings of fertilizers, mainly expensive organics, were applied and these maintained yields, but with a fall in price of pepper a switch to inorganic fertilizers took place. Yields then fell drastically and the economic cycle of the plant dropped to only one to three years with the bulk of the total yield in the first year of production. The fall in yield appears to have been due to the inexperienced use of unbalanced fertilizers, high in nitrogen and low in potassium and phosphorus which sometimes killed off the vines; furthermore these leached rapidly from the soil bared by clean weeding and exposed to rainfalls exceeding 150 in. per annum with the lowest average, 7 in/month.

3.5.2 The literature does not indicate whether a successful fertilizer policy with inorganic fertilizers has been evolved. Certainly the large amounts of fertilizer needed, the poor buffering capacity of the soil, the excess of rain over evaporation in every month of the year and the farming system whereby the soil is kept bare, combine to make the use of soluble fertilizers a major problem. It is unfortunate that, in these investigations no soil analysis, to follow the fate of the fertilizers, appears to have been done.

3.5.3 Pineapple The pineapple industry was once based on plants grown as a catch crop in young rubber; however, decline in fertility and soil erosion forced the industry off these upland soils and on to the peat soils. Now pineapples, covering something of the order of 45,000 acres, are grown entirely on the deep forest peats. Dunsmore (1957) describes the technique of clearing the forest from the peat and planting the pineapples and shows that little fertilizer was used at that time. Kanapathy (1958) quotes results from fertilizer trials that show a yield increase from 17,000 lb/fruit/acre with K_0 to 25,000 lb/acre with 200 lb/K_2O and an increase in average fruit size from 2.65 to 3.10 lb. Another experiment is described by Tay et al (1968) in which yields increased in both nitrogen and potassium treatments, the outstanding response being to potassium with an increase from 11.6 tons/acre at 100 lb K_2O to 13.8 tons/acre at 300 lb K_2O; there was no response to phosphorus. Fruit size, sugar and acid content also responded very significantly to potassium fertilization. The yield in the experiment, 12 to 13 tons of fruit/acre, is about 2½ times that obtained by the commercial plantations.

3.5.4 Pineapples on peat suffer from a marked deficiency of copper. The term "green die back" has been used for this disease in which the leaves of affected plants are a brighter green than the leaves of healthy plants and are thin and narrow and notably erect. Successive leaves produced by affected plants are shorter and they may die if not treated. It has been found that this disease can be controlled by applying copper sulphate either in the fertilizer mixture or as a foliar spray as Bordeaux mixture. It is suggested that annual applications of 5 to 10 lb of copper sulphate will control the condition. A deficiency of zinc, "crook neck" has been suspected and zinc sulphate is recommended at the same levels as copper sulphate.

3.5.5 The pineapple industry on peat is of considerable interest for it appears to be the only well established large scale agricultural development of forest peats in the tropics. Though there are many problems of drainage, clearance of the wood and stumps and transport over the soft peat soils, the cultivators manage to produce very acceptable yields for the canning industry when good cultivation practices are used. Although pineapples are grown continuously on the same land as in other pineapple growing countries there appears to be no nematode problem; whether this is a factor of the peat soils or of the generally low yields not showing up serious attacks, is not known.

3.5.6 Cocoa At one time the Department of Agriculture regarded cocoa as a potential alternative to rubber in Malaya and a fairly intensive programme of varietal introductions and fertilizer trials was started. The early trials indicated a significant growth response to Christmas Island rock phosphate but not to other fertilizers (Allen 1953). However many of the plantings suffered from a severe "die-back" with which symptoms of leaf chlorosis and necrosis were frequently associated and have been described in detail by Turner (1968). Because this problem could not be elucidated, Government policy on cocoa was changed and it was decided that it should not be recommended to farmers (Haddon 1961).

3.5.7 The symptoms have been reported on soils from a wide range of parent materials, though they are less severe on soils from coastal alluvium. There is some indication that low levels of calcium may be responsible, for the disease is at its most severe on the highly weathered, highly leached soils with less than 0.1 me/100 g exchangeable calcium, and the symptoms resemble those described by Lockard et al (1959), who found that cocoa was particularly susceptible to calcium deficiency. Leaves from "die-back" plants often have very high manganese levels, sometimes exceeding 1000 ppm (Allen 1966). Thus the available evidence, better growth on soils of coastal alluvium with exchangeable calcium levels >3 me/100 g, high manganese leaf levels, symptoms resembling those for calcium deficiency in sand culture and response in growth to calcium phosphate, suggests that calcium nutrition is implicated, but liming has not cured the problem. However even with heavy dressings of lime, much of the calcium remains close to the surface and it is possible that cocoa, like cotton, is sensitive to low calcium and high aluminium levels in the subsoil.

3.6 Cover Crop Legumes

3.6.1 As Malayan soils have low pH and low calcium levels the behaviour of legumes under such conditions is of particular interest, especially as they are now grown over a very large area and form a standard part of the technique for establishing oil palm and rubber plantations. With the present rate of new planting and replanting of rubber and oil palm, several hundred thousand acres of legumes are under cultivation. Leguminous covers have not always been used in the plantation industry; Watson (1957a) reviewing the use of covers points out that in the early years of the industry, clean weeding was much favoured, for practical experience showed that young rubber grew best in the absence of competition, but serious erosion and the enforced economics brought about by price decline forced the planters to abandon clean weeding. There then arose a system of planting creeping legumes, mainly Pueraria phaseoloides, Centrosema pubescens and Calapagonium mucanoides, as covers. Normally the seed is pre-treated, inoculated with rhizobium and often sown together with phosphate dressings. In the first three years of the plantation the covers grow vigorously though they may have to be weeded of grasses; competition with the young trees is limited by keeping strips or circles around the trees bare. As the leaf canopies develop, increasing shade depresses growth of the cover crops and indigenous plants that are more shade tolerant become established so that the leguminous covers are virtually eliminated when the canopy is fully established. At full canopy the soil may be protected only by the leaf litter from the rubber trees. Because of the importance and the expense in establishing legume covers there has been a considerable amount of investigation into the amount of nitrogen fixed, the best conditions for growing the plants and the influence of different covers on rubber and oil palm growth and yield.

3.6.2 Amount of nitrogen fixed. By growing inoculated Centrosema in sand culture with no nitrogen fertilizer the equivalent of 250 lb/acre of nitrogen was obtained in four months growth (RRI 1940). When plots of bare soil were compared with those with leguminous covers, the latter were found to contain 460 lb more nitrogen per acre than the former (RRI 1954). Watson (1957b) estimated the amount of nitrogen fixed by Centrosema in a pot experiment with presence and absence of sulphate of ammonia, urea and sodium nitrate; a non-legume, Mikania cordata, a creeper of the Compisitae family was used as a comparison. In the absence of nitrogen this grew little but the legume grew vigorously. The amount of nitrogen fixed was calculated from the amounts in the vegetation and from that lost by leaching; Centrosema fixed the equivalent of 210 lb of nitrogen per acre in five months in the absence of nitrogen fertilizers and 136 lb/acre in their presence.

3.6.3. Watson points out that because of the relatively large amount of nitrogen originally present in the soil, 20,000 mg per pot, compared with 300 mg. in the plants and leachates, detecting changes of total nitrogen in the soil is very difficult and likely to be masked by soil variability. This point is emphasized by Table V from a small scale trial ($\frac{1}{100}$ of an acre plots) by Watson et al (1964c). The trial was fertilized with rock phosphate and 0.375 cwt/acre of a 10.17.4 nitrogen, phosphorus and potassium mixture.

Table V

Amounts of nitrogen under different covers in 0-6 in. horizon (per cent)

Crop	2nd Year	3rd Year	4th Year
Legumes	0.140	0.142	0.144
Grass	0.130	0.125	0.123
Natural Cover	0.119	0.128	0.124
Bare Soil	0.099	0.107	0.095
S.E.	0.024	0.020	0.015
Minimum 5% S.D.	0.024	0.020	0.015

This table indicates that although the total nitrogen was in the order, legumes > grass, > natural cover, > bare soil, the only significant difference was between bare soil and grass or legumes and that, only in the second and third year after clearing from jungle and planting the legume. It was not until the fourth year that the soil under legume had significantly more nitrogen than soil under grass or natural covers.

3.6.4. In a large scale field trial, Watson et al (1964a, 1964b) compared grass covers with leguminous covers. They found that the legumes returned to the soil, between the third and fifth years after establishment, a total of 215 lb/acre of nitrogen with 88 lb of nitrogen held in the green material at the end of the fifth year; comparable figures for grass were 20 and 44 lb of nitrogen per acre.

3.6.5. These experiments demonstrate the care needed when attempting to assess the nitrogen fixed by legumes by measuring the nitrogen increase in the soil, and they also show that where legumes grow poorly very little nitrogen is added to the soil. The results indicate that, under Malayan conditions, well grown legumes add between 100 and 200 lb of nitrogen/acre/annum to the soil. This may be a conservative figure for it does not take into account the nitrogen from the roots; Chandapillai (1968) showed that the weight of roots was about 70 g. per plant after 12 months growth, corresponding to perhaps 1 to 2 tons of dry matter per acre.

3.6.6 Nutrition of Legumes . Early pot experiments by Hamilton and Pillay (1941) showed that Centrosema growth was improved by applications of phosphate, basic slag giving the best results. Practical experience confirmed that legumes benefit from phosphate and its use became an established part of cover crop culture. Response to types of phosphate on different soils was examined by Watson et al (1963) in a series of experiments which included comparisons of basic slag with rock phosphate, presence and absence of sodium molybdate and inoculated and non-inoculated seed. Dead litter was collected and green matter production measured. Phosphate response depended on soil type, no response being recorded on the rich coastal alluvial soils but a response was found on the inland soils of low phosphorus status; the weight of nitrogen returned to the soil in the litter between the second and fourth year after planting was approximately 100 lb for the P_0 plots and approximately 160 lb for the P_1 plots, similar levels of nitrogen still being held in the covers at the end of the fourth year of planting.

3.6.7. Though basic slag and rock phosphate were applied on the basis of equal weight, not on equal P_2O_5 content, the former gave rather better growth and visual records indicated its superiority in the first year of growth. The authors suggest that the free lime and perhaps magnesium of the slag may account for this. A dressing of 450 lb magnesium limestone, included in one of the experiments, counteracted the decrease in magnesium in the legume brought about by rock phosphate which sometimes decreased the nitrogen content also. In this experiment neither molybdenum nor innoculation had any effect.

3.6.8. The influence of liming and molybdenum on <u>Centrosema</u> and <u>Pueraria</u> grown in pots was examined by Watson (1960) using three inland and one coastal clay, all with a pH below 5 and with total molybdenum contents of 0.92 and 3.84 ppm. Exchangeable calcium in the inland soils varied from 0.07 to 0.61 me/100 g;

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that for the coastal clay was 3.23 me/100 g. The soils were limed to pH's of 6 and 7 and the equivalent of 1 lb/acre sodium molybdate applied. The main effect of lime was to sharply increase the calcium and molybdenum levels and sharply decrease the manganese levels in the leaves and stems of the covers. There was an increase in dry matter by liming to pH 6 but liming to pH 7 caused the yield to decrease below that for pH 6. The dry weight of nodules per pot generally decreased with increasing pH; the author suggests that the increased nitrogen fixation could have arisen from more efficient nodule activity. The molybdenum in plants growing in the absence of lime or molybdenum was very low and the application of molybdenum to the soil increased both the molybdenum and nitrogen content of the plants. In the unlimed soil the nitrogen level of the leaf and nodule material was significantly correlated with the molybdenum content (r = .79). The application of molybdenum in the absence of lime also produced a significant increase in dry matter production by Pueraria and an almost significant increase for Centrosema.

3.6.9. The author remarks that because the lime increased molybdenum it was not possible from these experiments to measure the direct effect of the lime application; the effect of liming may be due to molybdenum being made more available. However, these experiments would indicate that the uptake of molybdenum was at limiting levels in the untreated soils. The effects of lime on molybdenum do not appear to have been repeated in field experiments and the greater soil volume explored by the roots of the legumes (Chandapillai 1968 records Centrosema rooting to 130 cm. depth) may provide the plant with sufficient molybdenum even in soils with such low levels.

3.6.10 Influence of Legume covers on growth of Rubber and Oil Palms. Since legume covers are not used for grazing their practical value lies in soil protection and improvement of rate of growth and/or ultimate yield of the permanent crops. The effect of leguminous covers compared with natural weed or grass covers has been examined in both rubber and oil palm; for rubber, in particular, the effect of legumes depends on soil type, the establishment of a leguminous cover having the greatest advantage on the poor soils.

3.6.11 On immature rubber, Watson et al (1964a), compared the effects of leguminous covers with a grass cover of Axonopus compressus and Paspalum conjugatum and a cover of Mikania cordata, a creeping Compositae. The rubber in the legume plots grew faster and was expected to reach tappable girth about 5 months ahead of the other plots. Mainstone (1969) reports that the yield in plots where rubber had been established with leguminous covers exceeded, by 20 per cent, that of the plots where the rubber had been grown with regenerating natural covers. The initial advantage of about 300 lb/acre in the first year of tapping fell off with advancing years. The legume plots also came into tapping 12 months earlier than those with non-legumes.

3.6.12 Pushparajah and Chellapah (1969) also confirm that tappable girth is reached earlier (3 to 13 months) in plots with leguminous covers. In comparing trees grown with leguminous covers and those with grass covers, using four levels of sulphate of ammonia, they found that extra nitrogen given to trees during immaturity could compensate for absence of legumes and their experiments suggested that for best growth, 3 to 4 lb of sulphate of ammonia per tree, between planting and maturity, should be applied with legume covers and 8½ to 12½ lb with grass covers. On this basis the legumes are reckoned to supply the equivalent of 4 to 8 lb of sulphate of ammonia per tree, i.e., 800 to 1600 lb/acre. The authors state that the rubber in the legume plot grew less well in the first year, a feature also recorded by Watson et al (1964a) and attributed this to competition between the young trees and the cover, even though circle weeding was done for the young trees. The advantage of leguminous covers is also recorded by Warriar (1969) in a series of experiments in which legumes reduced the period of immaturity by two years compared with natural covers. In the first 2½ years of tapping, yields of the natural cover plots were about 2,400 lb/acre less than in the legume cover plots; he too noted variations due to soil type.

3.6.13 Investigations of cover crops on oil palm have tended to follow the pattern set by rubber research, but they have been confined almost entirely to studying the effect on palm growth. Although a considerable number of experiments comparing different types of covers have been laid down, there are few published reports, most of the information being in the limited circulation annual reports of the commercial companies concerned. The effects on oil palm appear to differ from those on rubber, for leguminous covers give significant increases in yield on the coastal alluvial soils. Thus it is reported that over a period of 3½ years from the start of harvest, Pueraria plots yielded almost 7 tons of fresh fruit bunches more per acre than plots with *Mikania* and 2½ tons more than the plots with grass (Harrison and Crosfields 1966). In other experiments the value of legumes was compared with natural covers, with bare soil and with grass cover maintained with bi-monthly mechanical mowing. The grass cover gave the poorest growth and yield and the palms showed distinct signs of nitrogen deficiency. Young palms on all soil types need ample nitrogen so that any practice that interferes with nitrogen supply affects rate of growth to maturity and subsequent yields.

3.6.14 On inland soils the value of leguminous covers appears to be similar for oil palms as for rubber. Whilst covers are not needed on the coastal clays to prevent erosion and their function is thus one of weed control, in the inland soils early establishment of cover after felling and burning is necessary to protect the soil. As in rubber, the nutrient supply functions of the legume can be taken over by fertilizers so that the cost of legume establishment has to be balanced against the cost of an equivalent amount of fertilizers applied to natural covers.

3.6.15 Bevan et al (1966) sum up the position as follows - "in the absence of conclusive experimental evidence with respect to the affect of leguminous covers on oil palm growth and yield, no hard and fast rule can be applied when determining the cover policy for any given area. Generally, however, leguminous covers are favoured, particularly when planting on steep and undulating land following the clearing from jungle and/or rubber - leguminous covers are also recommended for situations where there is need to control the growth of strong weeds present in the natural cover".

3.6.16. This statement really sums up the position of leguminous covers in Malaya. The wide ranging investigations have conclusively confirmed that, given conditions for good growth, creeping legumes fix considerable quantities of nitrogen that are beneficial to the permanent crops. However, apart from this there is little to indicate that they perform other functions, that adequately controlled natural covers cannot perform, given fertilizers to compensate for the lack of nitrogen fixing capacity.

4. SOIL CHEMISTRY

4.1. Introduction

4.1.1. During the course of soil surveys and fertilizer trials many soil samples have been collected. Those from soil surveys have generally been from profile pits and normally the number of pits per soil series has been small. Though there have been some projects in which sufficient pits have been sampled to give an adequate measure of the variation in nutrient levels within a given soil series. Soils from fertilizer trials have been analysed in order to correlate levels of nutrients in the soil with fertilizer responses in pot and field experiments.

4.1.2. Chemical analyses have usually included determinations of carbon, nitrogen, exchangeable bases, cation exchange capacity, normally with ammonium acetate at pH 7, readily extractable phosphorus by various methods and "total" nutrients extractable with 6 N HCl. Some fractionations of phosphorus, potassium and nitrogen have been done. Trace elements have been determined on some soils, though there are no records of sulphur measurements except where it is in excess in acid sulphate soils.

Physical analysis have been confined almost entirely to mechanical analysis with a few measurements of surface areas but practically none of moisture characteristics. There are detailed descriptions of profile morphology for all the major soils and some micro-morphology studies have been done also.

4.1.3 The effect of fertilizers on the soil has been studied in a few experiments, nearly all on rubber, but with these exceptions there is relatively little information on the long term effect of fertilizer use on Malayan soils.

4.2. Total Nitrogen

4.2.1 An indication of the total nitrogen levels in top soils is given by Guha and Yeow (1966) who collected a large number of soil samples over several soil series on rubber estates. Their samples were taken from 0-6 in., rather too deep for a single sample as there is usually a distinct decrease below about 2-3 in. (Table VI). Their distribution diagrams show that, for a number of important inland soils 80 per cent of the samples had total nitrogen levels between 0.05 and 0.10 per cent; few of the remaining 20 per cent being above 0.15 per cent. The texture varied between silty clay and coarse sandy loam but the organic carbon and nitrogen levels were similar. The soils derived from basalt had a higher range, 0.11 to 0.25 per cent and the highest levels were on soils derived from coastal alluvium where 30 per cent of the samples had values exceeding 0.26 per cent. Few comparable ranges in soils under jungle have been determined, the value for soil under jungle (derived from basalt) is given by Panton and Ang (1958) in Table VI.

Table VI

Levels of carbon and nitrogen in a soil under jungle

Depth (in.)	Carbon %	Nitrogen %
0 - 1	4.60	0.31
1 - 3	2.56	0.20
3 - 6	2.05	0.16
6 - 12	1.66	0.11
12 - 18	1.40	0.12
18 - 30	1.09	0.10
30 - 42	0.89	0.08
42 - 54	0.77	0.07

Very little information is available on the losses of nitrogen which take place when jungle is felled and burnt. Watson et al (1964c) found that the total N in a soil kept bare for 8 years after clearing from jungle dropped from 0.13 per cent at clearing to 0.092 per cent, equivalent to the loss of 830 lb/acre of nitrogen but they found that the major part of the nitrogen loss occurred in the first 4 years.

4.3 Nitrification

4.3.1 Guha and Watson (1958) incubated three soils, a Selangor series (coastal alluvium), a Rengam series (granite) and a Serdang series (quartzite) with pH's of 5.1, 5.4 and 4.6. Although the authors do not specifically say so, it appears that the soils were air dried before incubation. The soils were incubated alone, with sulphate of ammonia at 4.3 cwt/acre, with $CaCO_3$ at 133 lb/acre and with $CaCO_3$ at 4 tons/acre; they were also incubated with a selection of organic materials including those from leguminous and non-leguminous cover crops, rubber leaves and the grass Imperata cylindrica.

4.3.2. A comparatively high level of ammonification was followed by the development of only a low level of nitrification, the soil with the lowest pH exhibiting the lowest rate. Amounts of nitrogen mineralized were low and were not related to total nitrogen in the soil. Sulphate of ammonia only slightly affected the soil reaction and no significant effects on the mineralization process were noted with it, nor with 133 lb/acre $CaCO_3$. However $CaCO_3$ at 4 tons/acre caused major increases in both pH and nitrification rate. The addition of large amounts of decomposable organic matter as leguminous material with a low carbon/nitrogen ratio (20:1 or less) resulted in high rates of ammonification and subsequent nitrification but senecsent rubber leaves and Imperata with high (27.9 and 61.2) carbon/nitrogen ratios did not mineralize at all in 70 days. With 4 tons/acre $CaCO_3$ nitrification started in one soil after 30 days incubation, but in another soil only after 60 days.

4.3.3 Further investigations on a large number of soil series (RRI 1967) showed that on prolonged incubation 5 to 10 per cent of the total nitrogen mineralized except in one soil, the Selangor series, in which only 1.3 per cent of the total nitrogen mineralized. However Table VII shows that when this soil was incubated without air drying and pulverizing, nitrification proceeded normally; similar results were obtained with fresh and air dried peat (RRI 1968).

Table VII

Effect of air drying on nitrification (mg/100 g soil)

		to NH_4	to NO_3	Total	pH
Selangor Series	Fresh	0	12.4	12.4	3.8
(0 - 6 in.)	Air Dry	7.9	4.7	12.6	4.3
Peat	Fresh	27.4	18.7	46.1	3.7
	Air Dry	46.5	2.8	49.3	4.2

4.3.4 Liming the Selangor series to near neutrality quickly released about 50 ppm of NH_4-N, but did not immediately effect nitrification, though there was a rapid and complete nitrification of the accumulated NH_4-N in both limed and unlimed soils two to three weeks after the start of incubation; thereafter the liming sustained a two to three-fold increase in the nitrification rate. Fractionation of the organic matter showed that nitrogen liberated by dilute acid hydrolysis accorded more closely with the nitrogen mineralized during incubation than did the large amount extracted by mild alkali.

4.3.5 Mikaye (1964) measured the NH_4-N in non-incubated fresh soils from padi fields throughout Malaya. He found relatively low values from 1-7 mg/100g soil in soils with total nitrogen ranging from 100 to 500 mg/100g; 1 to 14 per cent of the total nitrogen was ammonified on incubating air dried soils and there was a significant, though very low, (r = 0.49) correlation between NH_4-N produced on incubation and total nitrogen. In fact a better correlation (r = 0.69) was found between moisture content of the soil at the time of sampling and the NH_4-N produced in an incubated air dried soil.

4.3.6 The effect of Mikania cordata on nitrification forms an interesting aspect of nitrification of Malayan soils. Wong (1964) states that rubber grown with Mikania covers showed depressed levels of nitrogen and phosphorus in the leaves, depressed rooting in the litter layer and developed relatively small canopies. Depression of yield compared with leguminous covers has been noted in oil palms (Harrison and Crosfields 1966).

4.3.7 Wong used water extracts of Mikania for incubation experiments, the extracts being made from 2.5, 5 and 10 g of oven dried material in 100 ml. of water; similar extracts were made from Pueraria and Paspalum. Extracts of Mikania significantly decreased the rate of nitrification which was almost completely suppressed with the 10 per cent extracts of the plant material. Petroleum ether extracts of the roots of Mikania were made and these were separated on column chromotography, the compounds being identified as a mixture of phenolic and flavenoid substances. These compounds depressed the growth of the root attacking fungi, Fomes lignosus. However, although depression of nitrification was marked in some it was not consistent for all soils; furthermore since rubber can take up NH_4-N as well as NO_3-N (Bolle-Jones 1955) the reason for the depression of growth and uptake by the rubber tree is obviously not solely connected with suppression of nitrification.

4.3.8 No clear picture has so far emerged from the work on nitrification of Malayan soils. Soil type, pH, amount and type of organic matter and most important, soil drying, all affect the rate of mineralization, particularly the nitrifying process.

4.4 Effect of Nitrogenous Fertilizers on Soils

4.4.1 Because of their long term nature, fertilizer experiments on tree crops afford excellent material for studying the effects of fertilizers on soils, but such investigations have been confined mainly to rubber experiments. These have the advantage that the normal practice in young rubber is to spread the fertilizer in strips or in the weeding circles; only when the trees are mature is the fertilizer broadcast over the whole area. Thus Bolton (1961) was able to sample both treated and untreated plots and treated and untreated areas within plots. In a coarse sandy loam soil, using 0-12 in. samples and 24 samples per treatment, he found a highly significant depression of pH (from 5.3 to 4.4 in 1:5 soil/water ratio) where 24 lb of sulphate of ammonia per tree had been given over a period of 9 years. On a loamy clay soil, derived from shale, 14 lb of sulphate of ammonia per tree in 6 years depressed the pH from 4.7 to 4.1. Sulphate of ammonia also significantly depressed exchangeable calcium from 0.04 to 0.02 me/100 g in one soil and from 0.09 to 0.05 me/100 g in another. Rock phosphate prevented both the drop in pH and the loss of exchangeable calcium; no measure was made of the loss of exchangeable magnesium which is probably more important than calcium for rubber.

4.5 Leaching of Nitrates

4.5.1 Bolton (1968) did lysimeter experiments with bare soil to measure the leaching of nitrate and cations after application of sulphate of ammonia, rock phosphate, muriate of potash and magnesium sulphate. Soils of pH 4.8 and 5.2 were used and the nitrate derived from the sulphate of ammonia and leached through the lysimeters was measured. Appearance of nitrate in the leachate was more rapid in the soil with the higher pH. About 90 per cent of the applied nitrogen was recovered in the leachates after application of 30 to 50 l. of water to about 50 kg. of soil in cylinders 60 cm deep. Concentration of cations in the leachate was related to the concentration of anions, especially nitrates and chlorides. The practical implication of using bare soil arises from the fact that, before planting rubber or oil palm the soil is bare for several months because of felling, clearing and burning. The planting rows, about a quarter of the total area, are kept free of weeds for at least 18 months, though during this period the young tree roots ramify throughout the surface soil.

4.6 Volatilization of Ammonia

4.6.1 Loss of ammonia by volatilization was investigated by Watson et al (1962) in a series of field tests using 200 lb/acre pelleted urea, applied to a sandy loam soil with cation exchange capacity of less than 3 and in clay soils with cation exchange capacities of 14 to 25; the pH values in all soils were around 5. Losses from the clay soils were negligible under all conditions. In very dry conditions, i.e. a soil moisture content of less than 1 per cent there was little loss from bare sandy soil; losses from urea applied to soils in very wet conditions were also small. The largest losses were on the sandy loam soils with moisture contents of 4 to 10 per cent under cool conditions when cumulative losses of 24 per cent were recorded over 8 days after application. When the urea was applied on a surface covered with the litter of rubber leaves up to 15 per cent was lost after application with a possibility of cumulative losses reaching 20 per cent. Even greater losses, up to 28 per cent occurred when the urea was applied on the surface of cover plants. Thus it is recommended that urea should not be broadcast on moist loam or sandy loam soils drying out after rain or on cover plants or leaf litter in hot sunny weather. Although loss of ammonia by volatilization can be prevented by cultivating the fertilizer into the soil - a function performed nearly as well by rain washing it into the ground after application - cultivation other than by hand in many rubber areas is impossible. However, because of its low price per unit nitrogen, it may be better economics to apply urea and suffer some loss than to apply other more expensive fertilizers from which losses do not take place.

4.7. Phosphorus Status

4.7.1. The widespread responses to phosphorus especially on the inland soils of a variety of crops, including young rubber, oil palms, legumes, cocoa and in many areas rice, have been discussed. Phosphates have also improved yields of rice from fish ponds in acid sulphate soils, once the pH of the water in the pond has been brought to neutrality (Watts 1968). Because of the obvious importance of phosphorus the phosphate status of Malaysian soils has thus received considerable attention.

4.8. Total Phosphorus

4.8.1. 'Total' phosphorus has been determined by Ng (1966) by igniting the soil and then extracting with 6 N HCl. His results show that most soils have less than 200 ppm total phosphorus, exceptions being soils derived from basalt and from coastal alluvium, which may have 500 ppm or more. Guha and Yeow (1966) collected a large number of soils from rubber estates and found that 90 per cent of the samples of inland soils derived from quartzites and shales had total phosphorus values below 250 ppm; some of the soils on basalt had levels of upwards of 200 ppm.

4.9 Fractionation of Phosphorus

4.9.1 Owen (1953) fractionated the phosphorus in three groups of soils using the method of Williams (1950) (an acid extraction with 2.5 per cent acetic acid containing 1 per cent 8 hydroxy-quinoline, an alkaline extraction using 0.1 N NaOH and a 'total' extraction by digestion with concentrated HCl.) Owen's values for the different fractions are given in Table VIII; he points out that the levels for acid soluble phosphorus in the inland loams and clay loams are extremely low by any standards.

Table VIII

Native Phosphorus in some Malayan Soils (ppm. P)

Soil 'type'	Inorganic P Acid Soluble	Inorganic P Alkaline Soluble	Organic	Inert	Total
Inland soils - loams, clay loams, mostly highly ferruginous	2	10	27	56	94
Inland soils - sands, sandy loams.	7	5	37	23	73
Coastal alluvium soils - clays and clay loams.	13	41	105	92	251

4.9.2 The effect of phosphorus fertilizers on the different forms of soil phosphorus were studied by Bailey (1967) in Sarawak on soils with an exchange complex dominated by aluminium; by adding monocalcium phosphate at 36 and 72 lb of phosphorus/acre, he increased total phosphorus, aluminium-phosphorus, iron-phosphorus and calcium-phosphorus significantly. The 'available' phosphorus extracted by the Bray and Kurtz solution (0.1N HCl + NH_4F), followed very closely the aluminium-phosphorus (r = 0.958) and maize height correlated well with the 'available' phosphorus (r = 0.62). The amount of phosphorus bound as aluminium-phosphorus from the fertilizer was influenced by application of muriate of potash (30 lb/K per acre); at K_0P_0 the aluminium-phosphorus was only about 5 ppm, at P_2K_0 23 ppm, but at P_2K_2 nearly 60 ppm.

4.9.3. The forms of phosphorus in rice soils were studied by Kawaguchi (1966); he found that, using the Bray and Kurtz solution, phosphorus extracted from the plough layer of padi soils varied from about 9 to 200 ppm of P_2O_5, the highest yielding soils having the highest values and the soils of the east coast, where responses to phosphorus by padi are widespread, having usually less than 10 ppm. He also measured the available phosphorus using the same extractant on air dry samples and on samples submerged for three weeks and kept at 40°C. The increase in extractable phosphorus was attributed to the increase in solubility of iron-phosphorus as aluminium-phosphorus or calcium-phosphorus would not be expected to change. The amount extracted increased by 1 to 8 times, with most soils increasing 3 to 4 times but the percentage increase appeared unrelated to the amounts in the air dried soil.

4.9.4 Kawaguchi also did a Chang and Jackson fractionation of some rice soils and the results are given in Table IX

Table IX

Phosphorus fractionation in some Malayan padi soils
(mg/100 g P_2O_5)

Sample No.	NH_4Cl (easily soluble)	NH_4F Al-P (Fe-P)	NaOH Al-P Fe-P Org.P	H_2SO_4 Ca-P	Citrate dithio- nate	NH_4F occluded Al-P	Sum	Total
29	0	1.6	9.5	3.2	7.6	0.4	22.3	58
42	0	0	11.1	4.1	6.8	3.7	25.7	62
18	0.2	1.6	22.6	16.9	11.4	0	52.7	99
15	0.4	6.8	18.9	15.2	3.8	2.1	47.2	136
14	0.2	5.3	4.1	28.4	3.0	0.6	41.6	55
43	0	30.5	65.5	5.9	16.8	1.5	120.2	198
24	0	10.5	3.3	0	4.6	0	18.4	92

Samples 14, 15 and 18 have high calcium-phosphorus probably from rock phosphate application.

4.10 Phosphate Fixation

4.10.1 Early laboratory experiments on phosphorus in Malayan soils were done by Owen (1947a); he found that phosphorus retention exceeded 50 per cent of the added phosphorus in nearly all soils, retention in the inland soils being closely correlated with the amount of clay and being exceptionally high in a soil derived from basalt. The readily soluble phosphorus fraction, as determined by conventional chemical methods, was roughly the same whether the soils were treated with soluble or insoluble forms of phosphate.

4.10.2 In a further series of experiments Owen (1953) incubated a group of soils with the equivalent of 10 cwt of rock phosphate/ acre for a year and measured the different forms of phosphorus. Results are given in Table X.

Table X

Forms of phosphorus as percentage of amount added

Soil 'type'	Acid Soluble	Alkaline Soluble	Total Recovery
Inland soils - loams, clay loams, mostly highly ferruginous	1.3	61.7	63.0
Inland soils - sands sandy loams	35.2	38.4	73.6
Coastal alluvium soils - clays and clay loams	25.8	74.9	100.6

Owen concluded that the phosphorus of both water soluble and insoluble phosphates, when added to ferruginous loams and clay loams, is precipitated as phosphates of iron and aluminium. In sandy soils and soils from alluvium the precipitation is much less complete. He also concluded that organic phosphorus is likely to be particularly important in the ferruginous clays and consequently suggested that adding phosphorus to the cover crops would form a useful method of providing phosphorus for the rubber.

4.11 Measurements of 'Available' Phosphorus

4.11.1 The phosphorus status of Malayan soils has normally been defined by measuring 'total' or 'reserve' phosphorus by digestion with a perchloric-sulphuric acid mixture or by 6 N HCl extraction of the ignited soil and by 'available' phosphorus using HCl-NH_4F extraction at pH 1.8. These methods will discriminate between soils with high and low levels of phosphorus but do not discriminate between soils with medium levels. Consequently measurements of quantity and intensity of phosphorus have been done (Mohinder Singh and Talibudeen 1969).

Intensity measurements were done in 10^{-3}M citrate in 0.01 M NH_4Cl and quantity measurements by isotopic exchange. Though both measurements could differentiate between manured and unmanured soils, only the quantity measurement was related to phosphorus uptake by Pueraria in glasshouse cropping; this ranked the soils in the correct order for plant uptake as did the normal 'available' P measurements.

4.12 Plant uptake of native phosphorus and phosphorus from fertilizers

4.12.1 A number of experiments, usually with pots, have reported the phosphate supplying power of unfertilized soils and the uptake of phosphorus from that given in fertilizers. Watson (1968) studied the recovery of Christmas Island rock phosphate and triple superphosphate added to a number of Sarawak soils, using spinach (Amaranthus) as an indicator plant. The proportion of phosphorus applied (up to 8 cwt/acre of fertilizer), taken up by two crops, was as low as 1.21 and as high as 8.1 per cent for rock phosphate; for triple superphosphate the values varied between 5.3 and 14.8 per cent.

4.12.2 Joseph (1965) used Pueraria to measure the uptake of phosphorus added as Christmas Island rock phosphate and monocalcium phosphate in a series of pot experiments. In two crops the amount of phosphorus recovered in the plant was about twice as much from the soluble as from the insoluble phosphorus treatments. The mean values for all soils for recovery of phosphorus added as Christmas Island rock phosphate was 22.1, 18.8 and 14.9 per cent for applications of 1, 2 and 4 cwt of fertilizer per acre. Watson's values for the recovery by spinach from Sarawak soils are much less.

4.12.3 The phosphate reserves in unfertilized soils were also measured by Pueraria in a series of pot experiments (RRI 1968). Dry matter produced, even with complete nutrient supply, varied greatly from soil to soil and the strongly structured soil the latosols on basalt give the highest yields. In no case did the cropping come near to exhausting the phosphorus reserves as measured by 'available' phosphorus before and after cropping. The differing ability of various crops to take up phosphorus from soil was shown by the grass Paspalam conjugatum which failed to establish when tried on a similar series of soils (RRI 1969). This work indicates that there is a very distinct difference in the ability of different plant species to make use of both native and fertilizer phosphorus in soils with active iron and aluminium fractions. Thus legumes and rubber appear able to make good use of low soil phosphorus levels whereas grass cannot. Attempts to grow maize as a catch crop in the rubber areas have shown that even on the coastal alluvial soils where there is ample phosphorus for rubber and legumes, maize failed to grow without phosphorus fertilizers (RRI 1968).

4.13 Movement of phosphorus in Soils

4.13.1 Since it appears that phosphorus is rather readily fixed in many Malayan soils, the behaviour of phosphate fertilizers added to the soil has had some attention, particularly their fate in relation to soil depth. Owen (1947b) examined the downward movement of phosphates by passing a solution of KH_2PO_4 through columns of soil; water was added at intervals for a month, the soils allowed to dry out, the columns sectioned and the phosphorus retained determined. The phosphorus penetrated to about 10 to 12.5 cm but over 70 per cent was held in the top 7.5 cm.

4.13.2 Bolton (1968) in a lysimeter experiment with a sandy latosol treated with rock phosphate and superphosphate, showed that HCl/NH_4F extraction indicated that phosphorus remained mostly in the surface 2.5 cm. There was a slight increase in soluble phosphorus at 2.5 - 10 cm from rock phosphate and a larger increase from superphosphate. Below 10 cm, soluble phosphorus was similar to values determined before leaching.

4.13.3 Middleton and Pushparajah (1966) found rather more mobility in pot experiments in which the downward movement of phosphorus from soluble and insoluble phosphorus fertilizers was compared. Phosphorus from both leached downwards, though slightly more from the soluble phosphorus fertilizer reached the 20 to 30 cm horizon.

4.13.4 Field experiments have also indicated that there is some movement of phosphorus down the profile; Table XI shows the movement of rock phosphate on Rengam soils (broadcast 1957, 1963 and sampled 1964, RRI 1965).

Table XI

Movement of phosphorus in a field experiment on a Rengam series soil (ppm P)

Depth of Sampling (in.)	P Determination	Level of fertilizer application (cwt/acre) 0	6	12	L.S.D. 5%
0 - 6	'Total'	145.7	240.4*	356.9*	62.0
	'Available'	4.1	43.8*	111.6*	28.7
6 - 12	'Total'	130.8	152.7	189.8*	23.0
	'Available'	3.1	11.0*	23.3*	6.9
12 - 18	'Total'	122.8	140.3	156.1*	21.0
	'Available'	2.6	6.1	13.7*	3.6

* Significantly different from the control.

4.13.5 The general picture emerging from studies of phosphate in Malayan soils is that there are only a few which are well supplied with phosphorus, and then only for some crops. Although there is evidence that phosphorus is fairly readily 'fixed' in many of the soils, particularly the ferruginous soils with an appreciable clay content, indications of considerable phosphorus movement down the profile and the long term residual effect of phosphorus fertilizers on rubber suggest that in the sandier soils at least, phosphate fertilizers have a long lasting effect.

4.14 Potassium Status

4.14.1 Although the potassium status of soils becomes more important as nitrogen and phosphorus deficiences are eliminated by fertilizers, soil potassium has not received much attention.

4.15 Forms of potassium

4.15.1 In a range of soils Ng (1965) did a study of the various forms of potassium dividing them into exchangeable, difficulty exchangeable, (a fraction extracted by boiling N HNO_3) strong acid soluble (concentrated HCl) and total (HF digest). Soils derived from granite, basic igneous rocks and quartzites are low in all forms of potassium, but some of the soils, derived from shales, have large amounts of illite which provides considerable reserves of potassium. The clay soils of the coastal alluvium, with mixtures of illite, montmorillonite and kaolinite, have also substantial reserves of potassium. Ng found some correlations between the various fractions but these were not consistent from soil to soil and the potassium extracted by strong HCl was not closely related to the total potassium in many soils. Table I shows that there is a considerable concentration of exchangeable potassium in the top 3 in. of soils with low potassium status. The total potassium levels in these soils are often below 0.2 per cent. Fixation studies revealed the expected pattern of low potassium fixation by the kaolinitic dominated soils, but the presence of illite or montmorillonite led to fixation.

4.15.2 The variations in exchangeable potassium by soil type has been discussed by Guha and Yeow (1966) for the 0 to 6 in. horizon of soils under rubber. Many of the inland soils have less than 0.15 me/100g, though some of the soils from granite may have 0.15 to 0.30 me/100g. Potassium is highest in the soils from coastal alluvium, 40 per cent of the samples having values exceeding 0.3 me/100g.

4.16 Leaching of potassium

4.16.1 Although heavy potassium dressings are recommended for oil palms on inland soils, there has been little study on the fate of such large amounts added to poorly buffered soils.

Bolton (1968) studied the leaching of muriate of potash added to a bare sandy latosol using filled-in lysimeters 60 cm. deep; he found that a significant proportion of the fertilizer potassium and magnesium added with sulphate of ammonia leached below 60 cm. in six months with the equivalent of 28 in. of rain. He also found that the sulphate ion was adsorbed more strongly than the chloride ion and so suggested that sulphate of potash might be a more efficient fertilizer than muriate of potash. The ratios of potassium, calcium and magnesium in the leachates were a function of those adsorbed on the exchange complex so that losses of potassium and magnesium could be lessened by increasing the calcium saturation of these largely aluminium saturated soils. Addition of calcium would be a cheaper way of displacing aluminium ions than would addition of potassium, but calcium is very slow to penetrate into the sub-soil because of the low solubility of the usual calcium compounds.

4.17 <u>'Available' potassium</u>

4.17.1 The normal method of determining potassium available to plants is extraction of exchangeable potassium with N ammonium acetate or N ammonium chloride and extraction with strong acid (6 N HCl); although these methods discriminate between the soils with widely different levels, they do not discriminate between the soils in the middle range. Consequently other methods including intensity measurements of potassium have been used; aluminium is used as the reference ion instead of the more widely used calcium ion because aluminium is a major ion on the exchange complex of Malayan soils (Mohinder Singh and Talibudeen 1969). Intensity values did not relate to the uptake of potassium by Pueraria in pot experiments. Potential buffering capacity of the soils, i.e., the rate of change of quantity with intensity, was related, but the potassium extracted by boiling for 1 hour with 6 N HCl gave as good a prediction overall. However, there was a suggestion that measurements of potential buffering capacity might discriminate between soils of low potassium status better than extraction with strong acid.

4.18 In conclusion it would appear that the relatively high concentration of the small amounts of exchangeable potassium in the surface of the poor inland soils, the leaching of potassium from the poorly buffered soils when fertilizer potassium is applied to crops with high potassium needs and the effect of magnesium status when heavy dressings are used, are all factors needing further investigation.

4.19 Liming, Calcium and Magnesium

4.19.1 The low pH of Malayan soils immediately suggested to soil scientists accustomed to temperate soils, that lime would be beneficial, and many liming trials have been done, but yield responses have been very few. Liming has been reported to improve the yield of coconuts on coastal alluvial soils (Wilshaw 1941), though it is possible that these were acid sulphate soils (Bloomfield et al 1968). A number of factors account for the lack of response; oil palms and rubber thrive on very acid soils with very low calcium and in fact high calcium interferes with the properties of rubber latex. The pH of rice soils, as measured in the air dried state is usually around 5 but the values rise towards neutrality on waterlogging and padi soils are generally relatively well supplied with calcium. The work on leguminous cover crops substantiates findings elsewhere that tropical legumes do not require high lime status soils.

4.19.2 Lime to supply calcium and/or raise the pH may be needed when new crops are introduced or when prolonged use of acidifying fertilizers drops the pH to very low levels. Examples of the former were noted for cocoa and the need for raising the pH has been found where maize is to be grown as an inter-crop with rubber; growth was much better on the ash from burnt trunks of old rubber (RRI 1968) and it is now recommended that 10 cwt of magnesium lime-stone per acre should be ploughed into the soil during land preparation for maize (RRI 1969).

4.19.3 The effect of sulphate of ammonia on soil pH has been discussed but so far there are no reports of lime having to be used to counteract the acidifying effect of fertilizers, though the widespread use of rock phosphate in conjunction with sulphate of ammonia does prevent undue acidification.

4.19.4 In contrast to calcium, magnesium is needed by both oil palm and rubber. Leaf symptoms associated with magnesium deficiency have been observed over large areas of mature rubber and Bolle-Jones (1956) has described the characteristic chlorosis. The exchangeable magnesium levels in soils where magnesium responses have been obtained are usually less than 0.10 to 0.15 me/100g (Bolton and Shorrocks 1961). The total reserves of magnesium are also very low, the amounts extracted by 6 N HCl ranging between 1 and 3 me/100g (Guha and Yeow 1966); only on soils derived from basalt or coastal alluvium are higher levels found. Bolton and Shorrocks reported that applications of magnesium limestone significantly increased the magnesium levels of the 0 - 12 in. horizon of soils.

4.19.5 Oil palms are also highly susceptible to magnesium deficiency and the symptoms of deficiency have been described by Coulter and Rosenquist (1955) and Turner and Bull (1967). In newly planted areas, symptoms are most likely on granite, peat and acid sulphate soils. Other soils brought into cultivation from jungle have larger reserves so deficiency symptoms are less likely. With prolonged cultivation and the use of ammonium sulphate and potassium fertilizers, soil types make less difference and deficiency symptoms can occur on both inland and coastal alluvium soils. Release of the large amount of potassium stored in old palm trunks by rotting may also cause transient magnesium deficiency symptoms in young palms.

4.19.6 Magnesium deficiency has been reported on maize (RRI 1968) but there are no reports of its need by other annual crops. The work on rubber and oil palm strongly suggests that magnesium levels in Malayan soils are low and that once advanced farming techniques using large quantities of nitrogen and potassium fertilizers are instituted, magnesium deficiency becomes of considerable importance.

4.20 Trace Elements

4.20.1 Although relatively few soils have been analysed for trace elements the levels in rubber and oil palm leaves have been determined for a large number of experimental and commercial areas. From these there is conclusive evidence that some trace elements are low in Malayan soils and deficiencies are particularly prone to appear when major nutrients are given in substantial quantities. Thus Middleton et al (1965) have shown that excessive lateral branching in rubber seedlings takes place when heavy dressings of soluble phosphorus fertilizers are used in pot experiments. The authors attributed this to a shortage of boron, copper and zinc within the plant; they suggest that this effect may be serious when marginal deficiencies of minor elements exist. They report that it can occur in young trees in the field and quote Mainstone (1963) as having shown a significant decrease in uptake of boron and copper when triple superphosphate was applied. Similarly, high magnesium has been reported in oil palms suffering from copper deficiency (Turner and Bull 1967).

4.20.2 Because the inland soils have been subjected to severe weathering and leaching low levels of certain trace elements are to be expected, but a need for sulphur, often deficient in such soils, has not been reported in Malaya. The reason for this is not clear though the widespread use of sulphate of ammonia for rubber and oil palms may be a factor.

4.20.3 Diagnosis of trace element deficiencies in Malaya has been aided by extensive sand culture experiments in which deficiency symptoms for both major and minor elements have been produced for the important crops (Shorrocks, 1964, for rubber and leguminous cover crops, Lockard 1959 for rice, Lockard et al 1959 for cocoa, Kanapathy, 1959 for pineapples). Levels of trace elements in various tissues of the oil palm are given by Ng et al (1968, 1969).

4.21 Arsenic

4.21.1 Sediments in some tin mine effluents may contain over 1000 ppm As_2O_3 (as arsenical pyrites) and these are sometimes deposited in padi fields. Lockard and McWalter (1956) examined the effects and described the symptoms of arsenic toxicity in padi grown in sand culture. One ppm did not depress growth but 5 and 10 ppm had a marked effect and the arsenic content of the plants rose to 5 ppm. They suggested that 3 ppm might be used as the upper level for detection of symptoms.

4.22 Boron

4.22.1 Turner and Bull (1967) state that slight symptoms of suspected boron deficiency are widespread in oil palm nurseries in Malaya. These symptoms are variously described as "hook leaf", "crinkle leaf" and "little leaf". Foliar spraying with 0.5 per cent borax solution has been used, although symptoms of toxicity can be easily induced.

4.22.2 "Hook leaf" and "little leaf" also occur in mature palms and the fronds of affected plants may have as little as 2 to 3 ppm boron compared with 10 to 15 ppm in normal plants; these low levels are associated with extremely high potassium levels in the fronds. Borax added to the soil appears ineffective but application in leaf axils brings about a dramatic recovery and leaf levels of boron rise within 2 to 3 weeks of application.

4.22.3 Boron deficiency has not been noted in other crops in Malaya but toxicity has been reported in rubber. This has been found on two distinct soil types, coastal alluvial soils, particularly those with a high water table and coarse sandy loams from acid granite where only a shallow layer of soil overlies the decomposing parent material (RRI 1964, Shorrocks

1964b). Sand culture experiments show that a typical symptom of boron toxicity, marginal necrosis, occurs when the leaf boron levels are 140 to 150 ppm; leaves from affected trees in the field had levels exceeding 100 ppm. It is considered that abnormal defoliation of the upper branches of rubber on coastal alluvial soils may be associated with boron toxicity.

4.23 Copper

4.23.1 Copper deficiency in the field has been reported only on peat soils. Dunsmore (1957) describes the symptoms under the name "green wilt" in pineapple and Turner and Bull (1967) described "peat yellows" in oil palm. The latter is usually typified by low levels of potassium (0.6 to 0.7 per cent), low levels of copper (1 to 4 ppm) and abnormally high levels of magnesium (0.4 to 0.5 per cent) in the leaf. In pineapple "green wilt" can be controlled by spraying with Bordeaux mixture, but in oil palm copper sprays can be phytotoxic and uptake of copper from soil applications appears very low. Copper applied to peat soils is probably fixed by the organic matter in a form unavailable or only slightly available to plants. Copper deficiency in rubber has been noted only under peculiar conditions, mainly in soil pot culture experiments where unusually heavy dressings of water soluble fertilizers have been used (Shorrocks 1964); under such circumstances the symptoms are transient and the plant recovers fairly rapidly. Some padi is grown on peat soils but attempts to improve growth by copper sprays produced scorch (Allen and Coulter 1957); the rice plant is not readily susceptible to copper deficiency for Lockard (1959) could not induce symptoms of deficiency in sand culture even though the same technique was successful for cocoa.

4.24 Manganese

4.24.1 Akhurst (1933) found that the total manganese levels in Malayan soils were low, averaging about 280 ppm. The exchangeable manganese is mostly less than 0.036 me/100 g but levels less than 0.0071 me/100g are frequently found (Shorrocks and Watson 1961). After Bolle-Jones (1956) had induced and described the typical symptoms of manganese deficiency for rubber, the widespread nature of this deficiency was recognized, particularly on soils on the old terraces. The deficiency is a simple one of low total levels in the soils since the acidity of Malayan soils is favourable for manganese uptake. Bolle-Jones (1957) described a manganese-magnesium antagonism in rubber seedlings grown in sand culture; increased supply of magnesium markedly decreased the concentration of manganese in the leaf lamina giving manganese deficiency symptoms; on the other hand increasing manganese could lead to decreasing magnesium uptake. He also found that, in the young stages of rubber plants, growth was more hindered by lack of manganese than by lack of magnesium.

4.24.2 Bolton and Shorrocks (1961) reported a striking reduction in the levels of leaf manganese in rubber, from 188 to 98 ppm, when 2 lb of magnesium limestone/tree were applied. Soil analysis showed that the reduction in leaf manganese could not be attributed to an increase in soil pH. In field experiments with 4 and 8 oz of manganese sulphate/tree (30 per cent manganese), visual assessment indicated an improvement in the foliage five months after the applications. In leaves without deficiency symptoms, leaf manganese averaged 88 ppm, those with severe symptoms averaged 19 ppm, whilst slight chlorosis was found at 50 ppm. In the second year of one of the experiments manganese sulphate gave a significant positive effect on growth of 10 year old trees. There was also evidence of a manganese-molybdenum antagonism for manganese treatment depressed molybdenum levels in the leaves.

4.24.3 In contrast to manganese deficiency in rubber on Malayan soils there are examples of suspected manganese toxicity in rubber on soils derived from basalt in Sabah where total manganese in the soil may be as high as 7000 ppm. Some of the Pueraria covers showed leaf chlorosis attributed to the excess of manganese preventing uptake of iron; the chlorosis was more marked in strips due probably to soil compaction by machinery during clearing (Watson unpublished report). Manganese is at a higher concentration in the top soil (Allen 1966). He records 1350 ppm total manganese in the 0-2 in. horizon, 740 ppm in the 2 - 14 in. horizon and 196 ppm in the 52 - 72 in. horizon. A very high uptake of manganese by cocoa on these soils is also reported by Allen who found values up to 2200 ppm manganese in the older leaves. These samples were taken in connection with "die back" of cocoa, and though there was no conclusive evidence that high manganese was the cause of this, iron and molybdenum were very low in the leaves so manganese interference was implicated.

4.24.4 Cobalt and nickel occur in quite large quantities on some of the soils derived from ultrabasic rocks in Sabah. Ng and Bloomfield (1962) report between 0.4 and 0.9 per cent nickel and 0.1 per cent cobalt on soils from serpentinised peridotite.

These levels are generally toxic to normal plants, and only xerophytic vegetation grows on the soil.

4.25 Iron, Molybdenum and Zinc

4.25.1 Shorrocks (1964a) reports that iron deficiency is observed at times in rubber but its occurrence is limited to the peat soils, humic sands and leached sands or in areas where a layer of shells has induced alkaline conditions. The occurrence of iron deficiency when manganese is in excess has already been noted.

4.25.2 Molybdenum is very low in some Malayan soils, (3.6.8), but only in pot experiments has there been an indication that legumes benefit from its application. Deficiency symptoms have been established in sand culture experiments for both rubber and cover crops but no examples of deficiency in the field have been reported (Shorrocks 1964a).

4.25.3 Zinc deficiency is responsible for "crook neck" in pineapple and "sickle leaf" in cocoa; the latter has been noted particularly where there is an accumulation of decaying timber or of ash from burning timber.

4.25.4 The pattern of trace element deficiency shows the strong interaction between major and minor elements in the poorly buffered soils and confirms the ease with which the equilibrium can be upset by the heavy fertilizer usage of modern agriculture.

5. SOIL PHYSICAL PROPERTIES

5.1 Texture and Surface Area

5.1.1 Mechanical analysis has been done routinely on Malayan soils but few other physical measurements have been made. Some values for surface areas are recorded in Table II and the clay mineralogy of a limited number of samples has been examined. The latter has not added greatly to the information which can be obtained from normal chemical analysis. Surface area measurements are of interest in showing quite high values for the Kuantan series, a soil derived from basalt. These surfaces appear inactive in base exchange phenomena since the soil has a surface area of 248 m^2/g and a C.E.C. of less than 5 whereas the Selangor series, with a surface area of 188 m^2/g has a C.E.C. of 16. Insufficient work has been done on these soils to explain the importance of the differences in the surface area characteristics.

5.2. Water Control

5.2.1. As the general rainfall distribution is good, little attention has been paid to the moisture storage ability of the soils though it is now recognized that droughts of even a few weeks duration can affect the performance of rubber and oil palm. Since annual arable cropping, except padi on the flat land, is not important, soil structure has been little investigated. Though soil erosion was very serious in the establishment of the early rubber plantations, a policy of cover crop establishment, as soon as the felled timber of the jungle or old rubber or oil palm has been burnt, has prevented serious erosion.

5.2.2. Most of the work on water control has been done for padi. The system of irrigation in the major rice areas is by inundation, the drainage outlets being closed and the general water level, which rises during the rains, is supplemented in the larger areas by water brought in by canal.

5.2.3. The very young marine clays near the coast are extremely soft and do not dry out except at the surface and their permeability values are practically zero, but the older soils are distinctly different. The profiles of some of these have been described by Phillis (1963) as having a hard cultivation pan through which the padi roots do not penetrate; below this is a drier soil proceeding into a waterlogged horizon with a high permeability. Thus there is in effect two water tables and Phillis suggests that where the hard pan is near the surface root room may be restricted to such an extent that crop growth is poor. Cultivation undoubtedly contributes to the hard pan but it exists even where cultivation is not done.

5.2.4. Though there is a generally held view that some downward percolation of water is beneficial in padi growing, Phillis found it to be negligible in soils giving sustained high yields. Experiments on the influence of water control on padi in tanks were done by Lockard (1958) and Matsushima (1962). Lockard found that, whilst increasing the depth of water appeared to decrease the number of tillers neither the rate of lateral movement nor the presence of stagnant water had any effect on yield. Matsushima also noted a clear trend that the deeper the water the worse the yield except where the soil was kept just saturated and he found that stagnant water tended to give the highest yield.

5.2.5. Very few conclusions can be drawn from the research into the physical properties of Malayan soils, largely because such properties have not been regarded as major limiting factors. Introduction of annual arable crops or intensive use of heavy machinery for weed control and harvesting on the coastal clays might well lead to compaction but this is not yet regarded as a problem.

6. PROBLEM SOILS IN MALAYSIA

6.1 Peat Soils

6.1.1 Peat soils are fairly extensive in Malaysia and are particularly important in Sarawak with 13 per cent of the total area consisting of forest peat. Peat covers enormous areas in South East Asia and the figure of 40 million hectares has been given for Indonesia. These acid peats, which have often less than 10 per cent ash, are formed from forest debris and have been described by Coulter (1957), Anderson (1964) and Hewitt (1967), (1968); the fertilizer needs have been discussed (3.3.7 and 3.4.9).

6.1.2 There are many problems in the use of these soils which are extensive in the easily accessible lowlands, where agricultural development is needed to deal with the considerable population pressure. Their physical conditions make them difficult and expensive to drain as internal water movement is slow and large amounts of buried timber must be cut in the making of drains. The normal practice is a few deep, > 5ft depth, drains, but experience on peat soils elsewhere suggests that a more intensive, shallow drainage pattern might be better. Transport over them is difficult and shrinkage, with drainage and oxidation, leaves the tree roots exposed and provides poor anchorage so that rubber and oil palms topple over. Nevertheless experience shows that, if nutrition problems can be overcome, rubber, oil palms, pineapples and in places padi grow quite well. Much research is, however, needed on the best ways of managing these soils. The recommendation at the moment is to leave them in forest if over 3 ft. deep in the raw state.

6.2. Acid Sulphate Soils

6.2.1. Acid sulphate soils, estimated to cover about ¼ million acres in Malaysia, are scattered throughout the coastal plains and the problems of their agricultural development have been described by Bloomfield et al (1968) and Chow and Ng (1968). According to Chow, 60,000 to 80,000 acres are marginal padi lands, the remainder being under rubber, oil palm, coconut or uncultivated. Levels of sulphur in the lower horizons of some of these soils are very high, Chow giving a value of 4.06 per cent in some of his samples.

6.2.2. There are many reports on the occurrence of acid sulphate soils throughout South East Asia as well as in Africa and in South America and they present a formidable problem for agricultural development. Where they are growing padi yields may be very depressed though there is no clear relationship between yields and levels of sulphur. The effects on yields of oil palm are well known, Bloomfield et al quoting 2-3 tons/acre fresh fruit bunches in affected areas compared with 8-10 tons/acre in unaffected areas. Raising the water tables so that only the non-pyrite horizons are drained gives spectacular increases in yield though several years must elapse before it can be decided whether this improvement is permanent. Fish ponds in these soils require both lime and phosphate before adequate yields of fish can be obtained (Watts, 1968). Although it would be preferable to leave these soils until better systems of management can be evolved, this is not always practicable for they occur as a patchwork in the otherwise good soils of the coastal alluvial plains, and drainage and irrigation schemes as well as estate development projects, often include a proportion of them.

6.2.3. In addition to the problem of acid sulphate soils in established rice areas, there is also the difficulty of deciding, in potential padi areas where sulphur is detected, whether drainage will lead to damage from sulphates.

6.2.4. The chemistry of acid sulphate soils has been presented in fairly simple terms as oxidation of pyrites to basic ferrisulphate and the subsequent formation of jarosite. However many factors control the oxidation of pyrite and more understanding of these might provide a better background for decisions on the reclamation and use of these soils.

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