ACID SULPHATE SOILS IN MALAYA

J.K. COULTER.

Tropical Soils Liaison Officer
Rothamsted

PREFACE

This report is based on a visit to Malaya from 23rd May to 23rd June, 1967 at the request of the Ministry of Agriculture and the Federal Land Development Authority. The visit was concerned primarily with acid sulphate ('cat' clay) soils, which have been planted with oil palm. Some opportunities were available to see other crops on these soils and to discuss certain problems of coastal alluvium soils, mainly use of the extensive peat deposits and methods of draining the flat, heavy clay soils.

Part I is a discussion of the information, obtained during the visit, from publications from Malaya and from elsewhere. Part II gives a number of recommendations for acid sulphate soils and suggests various investigations. Suggestions are also put forward for investigations on peats and for studies of water movement in clay soils.

During the visit much information was obtained from the Ministry of Agriculture, Federal Land Development Authority and the research and plantation staff of Harrisons and Crosfields (Malaysia) Ltd. The co-operation of many individuals within these organizations is gratefully acknowledged for their experiences and observations are major sources of information for the report. The help of Dr. Bloomfield and Mr. Kanaris-Sotiriou of the Pedology Department, Rothamsted is also gratefully acknowledged.

TABLE OF CONTENTS

SUMMARY OF RECOMMENDATIONS

1. In areas already planted with oil palm water control gates should be inserted in the field drains so that the water table can be kept about the top of the acid sulphate soil.
2. Irreversibly dried areas should be re-wetted by short term flooding and bunch mulching.
3. When the acid conditions are ameliorated heavy fertilizer dressings should be tried.
4. Experiments with liming and bunch ash should continue and leaching with brackish water should be done.
5. At present soils with horizons of pH less than about 3.3 and more than about 0.1 per cent sulphate at less than 36 in. depth should not be planted with oil palm.
6. Rubber, though appearing to be less effected by toxicity, is not recommended as an alternative to oil palm until more information has been collected on its yields on these soils. Fish ponds are a promising use for some areas, but padi is not recommended.
7. Further studies on peat soils, particularly on copper and potassium needs and on drainage systems are suggested as a preliminary to greater exploitation of these soils for oil palms.
8. Even higher yields of oil palms on coastal clays may be obtainable with better water control and studies on irrigation during dry spells are recommended.

P A R T I.

INTRODUCTION

Extensive deposits of alluvial soils, both marine and fluviatile, occur on the east and west coasts of Malaya. The estimated total area is of the order of 5 million acres. About 2 million acres may be covered with deep peat in Malaya[1] but in Sarawak peat soils cover 12 per cent of the total area, (about 3.6 million acres) and thus most of the flat land[2]. The coastal alluvium soils on the west coast of Malaya are of great importance, being fertile, easily accessible and covering a large area. The main crops on the non-peaty soils are rice, coconuts, rubber and oil palms. On most estates, rubber is being replaced rapidly by oil palms, which yield an average of about 1.5 tons of oil per acre from mature Deli dura palms[3]. Estates are also replacing coconuts with oil palms for the returns are much greater. If the present development continues oil palms are likely to become the most important perennial crop on the coastal soils, at least in terms of export earnings. In spite of their extensive acreage, the peat soils are comparatively little used but successful development for agriculture would be of immense importance to the country.

2. Scattered throughout the coastal deposits are areas of acid sulphate soils (the term applied to soils which develop high acidity on drainage) on which several crops grow rather poorly but on which soil

---

(1) Mal. Agric. J. 40, 188.
(2) J. Trop. Geog. 18, 7.
(3) Ibid. 17, 127.

palms do particularly badly. (Plate I.). Soil surveys done so far show that these soils do not occur in very large continuous areas but rather as isolated patches in otherwise good soils. Some of the patches may be of the order of 1,000 acres[4] but the majority of areas seem to cover at most a few hundred acres. Though it has been known for many years that these soils are scattered throughout the coastal alluvial deposits[5] [6] their widespread nature and their effect on growth of tree crops have been underestimated. No accurate estimate of their area will be available until soil surveys have been completed. Possibly 20,000 acres of rubber, oil palms and coconuts are planted on such soils and a figure of 50,000 acres in padi has been suggested[7]; in addition considerable areas are still in primary or secondary forest. Watts[8] gives the figure of 500,000 acres for the total area of these soils, but does not state how he arrives at this figure.

3. Although some acid sulphate soils have been planted to tree crops for 40 years or more there is little information on the effect on yields, except in the case of oil palm. Table I gives the yields obtained from some affected fields and for comparison the yields from similar material on normal coastal alluvial soils[9].

---

(4) Mal. Soil Survey Rept. No. 3/1965.
(5) Mal. Agric. J. 28, 352.
(6) Ibid. 35, 22.
(7) Priv. Comm. Dept. of Agric.
(8) Trop. Fish Cult. Res. Inst. Malacca. Rept. No. 1.
(9) Priv. Comm. Harrisons and Crosfield.

Table I.

(Yield of bunches, tons/acre.)

Year of planting	1961	1962	1963	1964	1965
1953	5.56	5.97	4.95	3.49	2.54
1952	6.98	7.56	6.41	5.45	4.27
1954	2.94	3.83	3.58	2.69	2.18
1959*	-	3.54	6.21	7.68	7.16

* Planting on non-acid sulphate soil.

(These yields are for individual fields; in a number of cases the acid sulphate soil occurs in only part of the field so that the yield of the affected area is probably less). Though rubber roots appear to suffer (Plate II) yields seem less affected by high acidity; some fields give about 70 per cent of the expected yield but others, equally acid, give normal yields. A number of badly affected oil palm areas were formerly planted in coconuts, also poor yielding. The low yields have been attributed to poor management but it is quite possible that soils were largely responsible; yield records of South Estate, Carey Island, for example show much variation from field to field and also a general decline from 1955. Padi has been planted widely on these soils but yields are very low, often not more than 600 to 700 lb/acre.

4. Peat soils are important, covering both a very large acreage of flat land and forming almost the only reserves of undeveloped flat land

on the west coast. Some areas carry good stands of timber; about 50,000 acres have been cleared for pineapples whilst a comparatively small acreage is used for coffee and vegetable growing. Rubber, coconuts and oil palms have been planted on peat soils but yields have seldom been high.

5. Moisture control for perennial crops on the flat coastal alluvium requires investigation. Fertilizer needs of tree crops on these soils are better known now but there is little knowledge of the right type of drainage or of the need for extra water during dry spells.

ACID SULPHATE SOILS

Description and classification

6. In recent soil surveys of oil palm estates[10] detailed profile descriptions have been given of drained acid sulphate soils. These soils were described as variants of the Selangor series, the major soil series found in the coastal areas. The three variants are:-

(i) Selangor series, with acid sub-soil: a soil with a non-peaty top soil and an acid sub-soil.

(ii) Selangor series, Old Lunderston variant: a soil with a peaty top soil and an acid sub-soil.

(iii) Selangor series, Sungei Samak variant: a soil with an irreversibly dried peaty top soil and an acid sub-soil.

7. In detail the Old Lunderston variant consists of:

(10) Harrisons & Crosfield Unpubl. Rept.

0 - 12 in.	Dark reddish brown (5YR 2/2) peat, quite loose and friable and well decomposed; the lower boundary with the second horizon is indistinct.
12 - 21 in.	Brown to dark brown (5YR 5/2 to 4/2) organic clay; fairly high percentage of partly decomposed organic matter; consistency rather greasy, structure sub-angular blocky, coarse, strong; no iron deposits and no mottling.
21 - 27 in.	Similar to second horizon but very many, pale yellow, deposits (2.5Y 8/4) associated with buried organic matter.
27 in.+	Almost structureless, grey brown, 2.5Y 5/2, very greasy silty clay, containing a high percentage of buried, partly decomposed sedges and grasses. There are many light yellow deposits associated with organic matter and the soil darkens rather slowly on exposure to air; the final colour after prolonged exposure is black, Y.5YR 2/0; within this horizon there is buried timber.

8. The Sungei Samak variant consists of:

0 - 3 in.	(Mixture of charcoal and peat) black (10R 2/1) very friable; breaks down generally into a medium crumb structure but there are lumps of compact peat up to 4 inches in size; generally the whole horizon is quite loose and dry and there is a very sharp boundary with

0 - 3 in. (cont.)

the second horizon. The peat can be brushed quite easily off the surface of the second horizon.

3 - 8 in. Very compact, dry, clay with strong, coarse prismatic and moderately, coarse sub-angular blocky structure; variegated matrix colour, dark grey (7.5YR 4/0) and brown (10YR 5/3); no iron deposits and no mottling; content of organic matter probably not very high; the coarse prismatic structure units are separated by quite wide cracks.

8 - 24 in. Light brownish grey (10YR 6/2) clay with strong, fine to medium sub-angular blocky structure, moderate medium prismatic structure and moderate to strong fine angular blocky structure. Distinct reddish yellow (10YR 6/6) iron deposits, mainly along root channels and dark reddish brown (2.5YR 2/4) iron deposits along coarse structure faces. In places the matrix colour becomes light brownish grey (2.5YR 6/2).

24 - 30 in. Grey brown (10YR 5/2) clay with very coarse sub-angular blocky structure; heavy, dark reddish grey (5YR 4/2) iron deposits along coarse structure faces; pale yellow deposits in places, generally along large root channels; some of these darken in air, generally in isolated spots only to dark grey

24 - 30 in. (cont.) (2.5Y 4/0); rather greasy consistency, fairly high percentage of buried grasses and sedges; movement of water through the soil at the bottom of the profile is rapid.

9. In other recent surveys undrained acid sulphate soils have been mapped as Linau series[11]. This soil is characterized by a very dark greyish brown (10YR 3/2) organic clay surface soil and a subsoil of dark brown mucks with considerable organic matter. Below these organic horizons is a structureless, dark bluish grey (5B 4/1) silty clay with a distinct sulphurous odour.

10. During my visit about 80 soil pits were examined; the soils of these can be classified into one or other of the variants described above but there are a number of features which deserve special emphasis. The pale yellow deposits occur as large blotches on ped faces, around old root channels and often very closely associated with pieces of buried organic matter such as leaves. In some of the root channels tubes of the pale yellow material, with an outer covering of reddish brown material, are found; in places there are numerous tubes, 2 to 3 in. long and about 1/4" diameter, of the reddish brown material only. In some badly affected areas there is an almost continuous film of the pale yellow material on the faces of drains and the drain spoil shows many yellow spots and blotches. (Plate III). Although most of the acid sulphate soils are clays, silty clays or organic clays, one area (in Carey Island Estate) consists of sandy loams with pale yellow mottles similar

---

(11) Mal. Soil Survey Repts. 2/65 and 3/65.

to those found in the clays. Such soils elsewhere have been called 'cat' sands.

11. The depth to the acid soil varies greatly, from less than 12 in. to more than 36 in. However the depth appears fairly regular in any particular area for there is normally little variation within one field. Though usually of considerable depth there are places (in Bagan Datoh Estate for example) where there is a layer of acid sulphate soil, in this case from 22 to 30 in., with non-acid soil above and below.

12. The acid layers are nearly always associated with buried organic matter. In some places e.g. Sepang and Carey Island Estates the fibrous roots of <u>Rhizophora</u> mangrove are seen but in the greater number of pits <u>Rhizophora</u> roots are not found; in these pits the organic matter consists of old palm roots, probably Nipah palm and much of the acid sulphate soils of Malaya is probably associated with former Nipah palm swamps. (Plate IV).

13. Because of the buried organic matter the soils have a very low bulk density. In the drained soils a very strong prismatic structure develops to about 2 ft. with a structureless greasy clay underneath. However in Lanadron Estate, which had a severe drought in 1963, this structure has developed to more than 3 ft., the prism faces being 2 ft. or more high, and 6 in. across; cracks between the prisms are at least one inch wide. Much water must have passed through these soils since 1963 yet the cracks have not closed and it appears that the sub-soils have undergone <u>irreversible</u> shrinking. Water moves out of the soil so rapidly that the palms suffer moisture stress and the yields, which

dropped severely after the drought, have not reached their former levels. The amount and depth of cracking greatly influences water movement in the soils, a fact illustrated by the variations in rate at which the soil pits fill; pits in soils with deep cracks or buried timber refill very rapidly, those with no deep structural development fill only very slowly. The water table records, now being kept by the estates, will give useful information on rates of water movement in these soils.

14. The irreversible drying, described in the Sungei Samak variant, is of great importance in acid sulphate soils since the volume of exploitable soil is limited by the acid soil below and the irreversibly dried layer on top. Irreversible drying is not found on pure peats, only on peaty clays. Irreversibly dried soils are described in the Fen area of England as 'drummy' soils[12] and in the Netherlands as 'rodoorn' soils[13]. Drummy peats have the property of drying to a hard brittle condition, are sometimes extremely acid and behave like coarse sand in that they will not take up moisture when wetted. The 'drummy' character is attributed to a coating of colloidal ferric hydroxide on the particles. The occurrence of 'rodoorn' soils is attributed to the precipitation of iron humates arising from acid peat water. The formation is hastened by cracking of underlying layers which increases drainage through the soils. Conditions of formation in Malaya are rather similar for the Sungei Samak variant, in which the coarse prismatic structure with wide cracks is usually present.

---

(12) J. Agric. Sci. 56, 197.
(13) Edelman. Soils of the Netherlands. 1950.

Conditions of formation

15. Much of the original work on acid sulphate soils was done in Holland and Sweden but latterly their widespread presence in the tropics has been recognized and investigations in Sierra Leone, Surinam, Vietnam and the Philippines have added considerably to knowledge of them. Usually the original source of sulphur is the sulphates in sea water; organic matter must be present for the microorganisms to reduce these sulphates to hydrogen sulphide which then reacts with iron, forming hydrotroilite, $FeS.H_2O$. This may pass to a cryptocrystalline form of pyrite, malnikovite $FeS_2.H_2O$[14]. Both are black and give the soils a black colour, even when present in small amounts, but the colour changes rapidly to grey on exposure to air, owing to oxidation of FeS. Thus the conditions for formation are a supply of sulphur, a highly reducing environment, the presence of mobile iron compounds and the retention of iron sulphides, once formed. These conditions are most often provided by the brackish water zone where the water has a low oxygen content, the rate of sedimentation is slow and the area is permanently waterlogged. This accounts for the rather irregular distribution of the soils in Malaya and the fact that they are found more frequently in the lower lying poorly drained areas.

16. In their natural waterlogged conditions these soils have much of their sulphur in the form of sulphides and the pH levels are about 5 to 6. It is the drier conditions, following drainage, which allow the sulphides to oxidize to sulphates and the very high acidity to develop. Oxidation is attributed largely to biological factors[15] and the rate

---

(14) Int. Inst. for Land Reclm. Drain. Bull. 3.
(15) Plant & Soil 11, 215.

is controlled by moisture content, form of sulphide and particle size distribution of the sulphide compounds. Undrained, the soils contain >60 per cent moisture but the optimum moisture content for sulphide oxidation is about 30 per cent. In air-dry conditions oxidation can proceed, but much more slowly. In the Sierra Leone soils, a stable pH value was attained after drying for 28 days[15]. Oxidation was rather slow at first but speeded up as soon as the soils were dry enough to crack. In areas already drained, the soils have low pH values which normally show little decrease on further drying (about 0.1 to 0.3 pH units in the Malayan samples).

17. There is no information on the form of sulphides in Malayan soils. Analogy with Sierra Leone conditions suggests that the greater proportion is polysulphides, malnikovite $FeS_2.H_2O$ and pyrite, FeS_2. This is supported by the fact that large quantities of the pale yellow basic ferric sulphate are found; this is not formed by oxidation of FeS, the main sulphide compound in gytta soils in Sweden[16]. Oxidation of pyrite is normally regarded as being important only below pH 3.0, the formation of sulphuric acid to bring about this pH coming from the oxidation of ferrous sulphide, which oxidizes rapidly in air at high pH levels. However Hart et al[17] suggest that fine particles of pyrite can also oxidize quite rapidly at high pH levels. As soon as drainage takes place the fine pyrites would oxidize quickly to give low pH^s and these low values would be maintained over a long period by the slow oxidation of the coarse pyrites.

(15) Plant & Soil 11, 215.
(16) Ann. Roy. Agr. Coll. Sweden 17, 425.
(17) 5th Meeting CROACUS 1963.

18. When pyrites are oxidized ferrous sulphate and sulphuric acid are formed in the first instance[14]. With excess sulphuric acid further oxidation results in ferric sulphate, $Fe_2(SO_4)_3$. This can hydrolize readily to give basic ferrisulphate $Fe_2(SO_4)_2(OH)_2$ and sulphuric acid. If calcium carbonate is present it neutralizes the sulphuric acid but in its absence, the usual condition in Malaya, since the rivers are flowing from non-calcareous areas, the acid reacts with the exchangeable bases on the soil complex. These are removed, breakdown of the clay lattice results and iron and aluminium, which are released, are then available for exchange reactions. Consequently these occupy most of the exchange sites and iron and aluminium (mostly aluminium) clays result. Pons[18] states that Al clays always have a very good structure and the well developed structure of Malayan acid sulphate soils reported in paras 7 and 8 confirms this.

19. The reactions described above take place when the soils are desalinized i.e. when they have no soluble salts in their oxidized state. If the soils are unleached and there are free soluble salts during oxidation then, according to Pons & Zonnefeld[19], less acidity develops and pH values in these conditions may be 0.5 to 1.5 units higher than in soil oxidized after leaching. Such soils have the good structure and apparently the same appearance as the toxic 'cat' clays and have been named by them 'pseudo cat clays'; they are regarded as fertile soils. Although this distinction would appear to be of great

---

(18) Cong. Agric. Res. Guianas Bull. 12, 141.
(19) Int. Inst. Land Reclm. & Improv. Publ. 13.

practical importance they give no adequate explanation of the reactions taking place. Possibly the sodium and potassium in the brackish water lead to the formation of jarosite, $KFe_3(SO_4)_2(OH)_6$ or natrojarosite $NaFe_3(SO_4)_2(OH)_6$. Both compounds have been identified in 'cat' clays in Guinea[20]. Whilst having a similar colour (pale yellow) as the basic ferrisulphates they appear to be much more stable and therefore less important as a source of acidity.

Sulphate and pH levels

20. On the Harrison and Crosfield's group of estates more than 300 soil pits had been sampled and results of pH and sulphate measurements were available for study. The highest sulphate level recorded in air dry samples was 1.75 per cent. Total sulphur had not been determined in any of the samples but during the visit a number of samples were taken in bottles, sealed and sent back to Rothamsted. The analyses for samples from Field A, Old Lunderston Estate, are given in Table II.

Table II.

Depth (in.)	pH		S extracted as SO_4 (per cent)		Total S (per cent)
	Wet	Oven dried	HCl extract	HCl after H_2O_2	
12	3.25	3.25	0.02	0.23	0.37
25	3.05	3.00	0.17	0.41	0.58
40	2.00	2.15	1.11	2.32	2.56

(20) Rep. Rothamsted exp. Stn. for 1965, 74.

For the HCl extract the dried material was treated directly with 2N HCl and for the HCl after H_2O_2 extract, the dried material was treated with H_2O_2 to oxidize sulphides, the excess H_2O_2 boiled off and the residue extracted with 2N HCl. This table shows the large reserves of oxidizable sulphur, especially at depth, in a field which has been drained for many years. It also shows that much higher levels of sulphate can be obtained by H_2O_2 oxidation than are recorded for air dried samples.

21. The pH values (in water) of samples from 300 pits are set out in Figs. I and II. These show that acid sulphate soils, in this instance soils with more than 0.1 per cent sulphate in any horizon, have lower pH values in all horizons, with particularly low levels in the third and fourth feet of the profile. The distribution of pH values is of considerable interest as few of the samples have values below 2.5. The pH value of any particular sample can vary considerably for, as indicated in para 12, the sulphur is closely associated with organic matter which has an irregular distribution. The minimum pH[s] which are attained under natural conditions in Malaya are illustrated in Table III.

Table III.

Estate	Situation	pH air dry
Sepang	Side of field drain	2.8
"	Side of main drain	2.6
Sungei Sedu	Spoil from pit	2.3
Carey Island	Drainside	2.4
" "	"	2.7
" "	"	3.0
Sungei Samak	Drain spoil	2.5

22. Generally the length of exposure of these soils is unknown though for some it is certainly several years. It would thus appear that under favourable oxidizing and leaching conditions pH values stabilize around 2.5. This is in close agreement with the results reported from Sierra Leone, Sweden and Finland and is attributed to the large amount of ferric iron which, brought into solution at this pH, inhibits the sulphur oxidizing bacteria. Thus it is only in the absence of much ferric iron that pH values below 2, reported for some soils, could occur. Four water samples taken from pits and drains in the acid sulphate areas had pH values of 2.6, 3.0, 3.1 and 2.6.

Effects of acidity

23. Under normal conditions i.e. absence of sulphates, the lowest pH value that mineral soils can attain is 3.7 to 3.8. This is the value given by samples which have been treated with sulphate of ammonia for over 100 years[21]. At this pH, aluminium is practically the sole exchangeable cation. As pH levels go below 3.8 there are increasing amounts of aluminium in the soil solution; the level of aluminium in solution is about 1800 p.p.m. at pH 3.3 but only 33 p.p.m. at 4.3[22]. The amount of aluminium in the soil solution is indicated by the water samples from the pits which, when neutralized, give large precipitates of aluminium hydroxide. In these soils the aluminium most probably occurs as aluminium sulphate.

24. It is generally assumed that it is Al^{+++} rather than hydrogen ions which are responsible for toxicities in acid soils and much is known about

---

(21) Rep. Rothamsted exp. Stn. for 1963, 240.
(22) Soil Sci. 20, 181.

aluminium toxicity and plant growth; less has been published about the influence of iron. In oil palms affected by acid sulphate soils, the first symptom is die back of the tips of the youngest fronds. On older fronds entire pinnae may be necrotic and may be tightly rolled. Palms suffering severely may show desiccation of all fronds, apart from the central spear and neighbouring fronds, and there may be many unopened spears. These symptoms are rather similar to those reported for aluminium toxicity on other crops. Leaf analyses show very low P and Mg levels with high K. The low P may be due to the high aluminium concentration whilst the high K is possibly due to very low Mg and Ca levels in the soil. The actual level of aluminium which palms will tolerate is not known accurately though hydroponic experiments with young palms suggest that they can continue to grow with very high levels of aluminium sulphate in the solution. In general palms on the soils showing no sulphate (Fig. II) were growing well and thus pH values between 3.9 and 4.2 seem perfectly alright. On the other hand on Bagan Datoh Estate some very good palms were seen at a point where the 'cat' clay horizon was only 12 in. from the surface. The top soil had a pH of 3.4 (wet) and the 'cat' clay horizon 2.7 (wet). In general roots of palms do not proliferate in this horizon though a few are always found in it and these may go straight through pieces of 'cat' clay. In one case the yellow material taken from around a root at 42 in. had a pH of 3.2 (wet) and 2.9 (air dry). However virtually none of the roots, which had penetrated the 'cat' clay horizon, had developed secondary roots and, where the depth to 'cat' clay was small, the concentration of roots in the surface horizon was intensive.

25. As a generalization it may be stated that where the 'cat' clay is below 30 in. and where there is no irreversible drying at the surface the palms are usually doing quite well. There are some exceptions, as in Bagan Datoh Estate (para. 22) and in Field 21B, Sungei Samak, where 'cat' clay starts at 32 in. yet palms are poor. Similarly in Field OPN 5 at Lanadron Estate yields have fallen off very considerably, though there is non-acid soil to 33 in. The possible explanation for the poor yields in this field is discussed in para 13 where it is suggested that irreversible shrinkage in the subsoil following a severe drought may give over-drainage.

26. Because of the influence of irreversible drying on cover growth it is not possible to say definitely how these are affected by pH. Where there is no irreversible drying and the pH of the surface soil exceeds 4.0, leguminous covers, grasses and ferns all flourish. At pH^s below about 3.7 all covers are poor and often non-existent.

Effect of leaching on acidity

27. Draining and leaching the toxic sulphates is often recommended for reclamation of acid sulphate soils. Certainly in laboratory experiments large quantities of sulphates can be leached from air dried soils; thus Kivenen[23] showed that on leaching 50g of a clay, of pH 2.5 with three leachings, each one litre of water, the pH rose to 3.3, 3.5 and 3.7 after successive leachings; however conditions are far removed from those in

(23) 4th Int. Cong. Soil Sci. IV 259.

the field and such results cannot be related to the field. Adding water equivalent to that in his experiment would require about 4.5 million gallons (200 in.) for each acre 6 in. of soil to be leached. Even in tank experiments[24] highly acid soils remained at a pH of about 2.0, in spite of copious leaching for several years. Although leaching is recommended for these soils there are no records of the time required under field conditions, but there are records that, even under high rainfall, acidity remains for many years. Wiltshaw[25] reports that a coconut estate in Malaya, well supplied with deep drains in 1930, (drains 6 ft. deep 500 ft. apart) had a pH value of 2.7 in a sample from 36 in. in 1940. Even more striking are the results given in Fig. III. This represents a cross section between two drains which were dug, in Old Lunderston Estate in 1961, as part of an experiment to study the effects of intensive drainage on acidity and growth of palms. Fig. III illustrate quite clearly that the whole profile has remained very acid. Obviously oxidation has been vigorous for pH^s of samples taken at 35 to 40 in. are close to those of long exposed samples (para 22). In these circumstances it is understandable that the palms, far from improving, have become worse under the intensive drainage.

28. Although leaching, under these conditions, is not as intense as under laboratory conditions, considerable quantities of sulphates are washed out. Thus the intensive drought of 1963 in Johore caused the formation of much aluminium sulphate which, when carried into the Muar

---

(24) K. Kanapathy. Min. Agric. Mal. 14.2.66.
(25) Mal. Agric. J. 28. 352.

river by the succeeding rains, flocculated the suspended mud and poisoned the fish. Three reasons are suggested for the persistence of high acidity when the soils have been drained. The first is a balance between sulphate formation and leaching which is controlled by the mechanism suggested in para 22 i.e. the inhibition of sulphide oxidizing bacteria by large amounts of iron and aluminium. Leaching the sulphates raises the pH but restarts the oxidation forming more sulphates and increasing the acidity again. The second reason is the inefficiency of leaching because most of the water goes through the major cracks leaving the mass of the soil unleached. The third reason is that discussed in para 17 i.e. the fine sulphide particles oxidize easily but the larger particles oxidize only slowly and so remain, as a source of sulphate, over many years. These are theories only and much experimental work is needed before the reasons for the long persistence of acidity are understood. Such work should also reveal the time required to raise the pH by leaching. On leaching the sulphates infertile aluminium clays, with a pH of about 3.8, would remain and lime and fertilizers will be needed to produce good crops.

Effect of liming on acidity

29. Liming the soils will remove the acidity, but the expense of the large quantities needed and the difficulty of getting lime deep into the soil, must be overcome. In an experiment at Bagan Datoh Estate, several methods of applying ground limestone were tried. These were: 12 tons/acre broadcast and hoed in, 2 tons/acre in 4 trenches, 2 tons/acre in 6 auger holes and 12 tons/acre in 12 auger holes round each tree. In the

trenches and auger holes lateral effect of the limestone was extremely limited, a sample of soil with lime having a pH of 6.2 and a sample, half an inch away, a value of 2.8. Considerable amounts of iron had been precipitated round the edges of the limestone 'pocket'. Measurements of pH were done in July 1965 (before application of limestone) and in December 1965 (after the application). The results are given in Table IV[26].

Table IV.

pH values in fresh sample

Treatment	2ft. from palm			8ft. from palm		
	1st ft.	2nd ft.	3rd ft.	1st ft.	2nd ft.	3rd ft.
Control No lime (July)	2.98	2.65	2.34	3.01	2.68	2.49
12 tons/acre broadcast "	3.02	2.32	2.10	3.12	2.86	2.44
Control No lime (Dec.)	3.18	2.93	2.58	3.12	2.72	2.87
12 tons/acre broadcast "	3.32	3.17	3.13	3.99	3.28	3.00

Lime has increased the pH, rather surprisingly, down to 3 ft. On the other hand it is surprising also that the pH in the top foot has not shown a greater increase.

30. An interesting aspect of liming of these soils is the work done at the Tropical Fish Culture Research Institute, Malacca[27]. This

---

(26) Priv. Comm. Harrisons & Crosfield's.
(27) Trop. Fish. Cult. Res. Inst. Malacca. Rept. No. 1.

Institute, which has a series of ponds situated on acid sulphate soils, found that 1 ton/acre limestone is sufficient to maintain optimum pH values in the surface soil at the bottom of the ponds, provided the water is limed to pH 7 at the entry into the ponds. This contrasts with the lime requirement of 17 tons/acre to raise the pH of the upper 10 in. to 5.5. Ponds in these soils also need phosphate for production of fish.

PEAT SOILS

Occurrence and use

31. Peats form a large proportion of the undeveloped flat land in Malaya and they are of even greater importance in Sarawak and Brunei. Small areas of peat in each of these territories are freshwater swamps with rather higher mineral matter, base content and pH but the peats are largely oligotrophic with low mineral matter, low base status and low pH. They resemble quite closely the raised bog peats of temperate climates but they are composed of forest debris, with much buried timber, in contrast to the sphagnum moss of raised bog peats. Both the raised bog peats and forest peats are very low in plant nutrients, have a high water table requiring drainage, and contain much raw organic matter. The age of some of the peats in Sarawak has been investigated by carbon dating. These were sampled to almost 40 ft.; at that depth the age is 4270 ± 70 years. The calculated rates of accumulation vary from 1.563 ft. per 100 years in the deepest peat to 0.727 ft. per 100 years in the shallower material[(2)].

32. Few crops grow well on Malayan peats and pineapples are the only crop grown on a large commercial scale at the moment although yields are

low by the standards of other pineapple producing countries. Oil palms, coconuts, rubber, coffee and many annual crops are planted in the peat soils. Annual crops, particularly vegetables, do well if the peat is burnt but rice is not successful. Interest in development of peat soils in Malaya arises from their close proximity to dense centres of population as for example in Selangor; often they form the only reserve land of coastal estates.

Chemical Properties

33. Many routine chemical analyses have been done on peat soils, but the results, calculated on a weight rather than a volume basis, are misleadingly high. The bulk densities are probably about a quarter of those of mineral soils. Using this correction factor on the values given by Parberry & Venkatachalam[28] the levels of potassium come fairly close to those for inland soils in Malaya but the levels of magnesium are higher and the levels of calcium very much higher than in such soils. In fact the values for calcium are much higher than those in coastal clays. With the exception of copper, not much has been reported about the trace element status of these soils. Copper deficiency occurs in pineapples and very low levels have been reported in young oil palm leaves (1-2 p.p.m. as against about 6 p.p.m. in palms on other soils)[29]. The peats are not well buffered for copper for the difference between deficiency and toxicity levels is not great. There is a possibility of manganese deficiency in oil palms on some peaty

---

(28) J. Trop. Geog. 18, 125.
(29) Harrisons & Crosfield's Priv. Comm.

soils (leaves with 50 p.p.m. as against 150-200 p.p.m. on other soils).

34. The exchange capacity of Malayan peats is very large, Parberry <u>et al</u>.[28] giving figures as high as 150 m.e./100g. No information exists, however, on the ease with which bases are released by the peat. In oligotrophic peats elsewhere potassium, for example, is very weakly held and is easily leached off the exchange complex when the peat is drained. Malaysian peats have a low pH, about 3.5 to 4.5, and a low base saturation, about 3 to 15 per cent. However exchangeable aluminium has not been determined; its absence would influence the effect of low pH.

<u>Physical Properties</u>

35. Peats hold large amounts of water: Parberry <u>et al</u>.[28] give moisture levels in drained peats of 74 per cent at the surface and 88 per cent at 18 ins. These figures presumably represent the amount of water held about field capacity but no values are available for the amounts held at wilting point so that the available water capacity cannot be calculated. In the undrained conditions the peats have much more water, perhaps up to 800 to 900 per cent. Drainage costs about two to three times that of coastal clays for the drains have to be dug by hand and much buried timber has to be cut. Drain spacings and depths are purely arbitrary as there is no information on permeability or water movement. Buried timber appears to encourage rapid lateral movement and it is possible that consolidation and oxidation decreases permeability.

36. Shrinkage in the first few years, after draining and felling the jungle is rapid - on Sungei Sedu Estate the depth of peat decreased from 6 ft. to $3\frac{1}{2}$-4 ft. in two years - but thereafter it is much less rapid. The roots of mature rubber and oil palm trees are normally exposed on the surface and, as a result, most trees lean rather a lot though they often continue to yield quite well. Although the surface of peats may become fairly dry they do not undergo the irreversible drying noted in the peaty clays.

WATER CONTROL IN COASTAL CLAYS

37. Though the rainfall in Malaya is well distributed recent studies of rainfall reliability suggest that there are two and sometimes three to four months of the year when rainfall is inadequate to cover the calculated evapotranspiration(30). Deficits may be greater than the monthly calculations indicate since much of the rainfall arrives in high intensity storms with considerable loss even in the flat areas, through the drainage system. Improved planting material and much fertilizer are being used on the coastal soils but oil palm yields might be increased still further by water conservation and control. Some of the oil palm estates are recording water table levels but there are neither records of run-off nor data on the available water capacity of the soil. Drainage of all alluvial soils is done by arbitrary spacing and depth of drains which take no account of the soil type. Permeability varies greatly; some of the river alluvium e.g. the Briah Series, appears

---

(30) P. Wycherley. R.R.I. Priv. Comm.

to have a very low permeability but some of the marine clays e.g. Selangor Series, develop a good structure on 'ripening' and appear to have a reasonably high permeability.

P A R T I I.

IMPROVEMENT OF ACID SULPHATE SOILS

38. The oil palm estates are confronted with two distinct problems on these soils. On the one hand is affected land already planted, estimated at between 4 and 5,000 acres by Harrisons and Crosfield's for their estates alone. On the other hand is reserve land in jungle, such as part of Carey Island and areas of old rubber and coconuts scheduled for planting or replanting with oil palms in the next few years.

Planted areas

39. In most of the planted areas the choice is between improving the yields and abandoning the fields. In the worst affected areas it is very doubtful if yields can be raised to the average for the good coastal clays, even with large expenditure. Possibly the best that can be attained is a yield that will make it worthwhile to keep them in production as part of a large unit. Even if the water table is lowered slowly, exposing only a small part of the potentially acid soil to oxidation, ameliorating these soils by drainage is such a long term project that, on the basis of present knowledge, it offers no solution. At the moment we can only recommend the insertion of water control gates in the field drains so that the water table can be kept about the top of the 'cat' clay layer, in most cases about 18 in. to 2 ft. The main drains should remain open so that they can receive flood waters. A high water table should also help areas like those in Lanadron Estate which were over-drained during the drought and which now appear to suffer from chronic over-drainage.

40. Raising the water table levels should also improve irreversibly dried top soils such as those found in Sungei Samak Estate though additional treatments may be needed for these soils e.g. short term flooding and bunch mulching. Flooding, or at least raising the water table close to the surface, would eventually re-wet these soils though the palms will suffer from prolonged water-logging. It is important to recognize areas in some of the young plantations, such as that in Carey Island, where bare areas already show irreversible drying. In such areas the water table should be held close to the surface for a short period each year.

41. Acid sulphate soils are low in nutrients and additional fertilizers will be needed; phosphorus and magnesium deficiencies are indicated by the leaf analyses but potassium may be needed also when physical conditions improve. Without experiments it is impossible to say what levels of dressings would be economic but fairly large dressings will probably be needed. Perhaps the best approach would be dressings of the order of 8-10 lb. rock phosphate, about 6 lb. kieserite or magnesium limestone and 4-6 lb. muriate of potash per palm in the areas where the water table is raised (excluding for the time being the very worst areas). Heavy dressings of bunch-ash should be tried in these areas. There is also a need for one or more fertilizer trials, perhaps with standard dressings of nitrogen and potassium and varying levels of phosphorus and magnesium, on these soils. Of course it must be emphasised that fertilizer trials are unlikely to show any useful results unless the acidic conditions are ameliorated.

42. The trials with limestone should be continued; unfortunately burnt lime is too expensive, otherwise its greater solubility would be an advantage. Liming would probably be most useful in those areas with 'cat' clay very close to the surface and where, for practical reasons, it would be impossible to raise the water table above this layer.

43. Since leaching with sea water has greatly improved yields on these soils in Sierra Leone(31) and British Guiana(32) it should be tried on a small area where sea or brackish water can be made available.

Areas for planting or re-planting

44. Fields which have been planted with rubber or coconuts and have thus been drained do not present any problems in detecting the presence of 'cat' clay; not only can the material be seen in soil pits but pH measurements on the soil and water in the pits confirm its presence. In these conditions the problem is one of setting up criteria for deciding whether the area should be planted with oil palms. There is not enough information to give specific criteria but, from the evidence collected during my visit, it seems that soils with acid sulphate layers at a depth exceeding 36 in. should be safe. Indeed a depth of 30 in. may be feasible provided there is not an irreversibly dried surface layer and the water table is kept at that depth or above. An acid sulphate layer could be defined as one with a pH of about 3.3 or less on the air dry soil and a soluble sulphate content in the air-dried soil

(31) L'Agronomie Tropicale 18, 800.
(32) World Crops 14, 370.

exceeding 0.1 per cent. Until more information is available about the amelioration of acid sulphate soils already planted it would be advisable not to plant any soils where the acid sulphate layer occurs at less than 36 in. depth.

45. Some estates have reserves which have not been cleared of jungle and have not therefore, been drained. Consequently there may be none of the usual 'cat' clay symptoms in the soil profile. Profiles revealing any of the following characteristics will, however, be suspect:

(i) Horizons with a soft or buttery consistency making the material difficult to extract with an auger.

(ii) Buried organic matter throughout the profile or in certain horizons, particularly semi-decayed <u>Rhizophora</u> roots or Nipah palm roots.

(iii) An odour of H_2S in the soil pits or auger holes.

46. However laboratory identification is more reliable and soils which develop a low pH and high sulphate content on drying are definitely acid sulphate soils. It is suggested that the same criteria be used in this respect as for the re-plant areas.

<u>Investigations on acid sulphate soils</u>

47. It is obvious that there are many gaps in the knowledge of acid sulphate soils and, whilst the scope of investigations which can be undertaken is limited, there are certain aspects in which further information would be particularly useful. Aerial photography of affected oil palm estates will show the pattern of distribution of acid sulphate areas;

it should be possible to extrapolate this pattern to coconut and rubber plantations suspected of having such soils. Much information is needed on the forms of sulphur in Malayan acid sulphate soils for these will determine the rate and amount of sulphate formation on oxidation. A knowledge of the amount and forms of sulphur should indicate the time needed for improvement by drainage and leaching and provide a basis for decisions on methods of reclamation.

48. Liming, fertilizers and leaching with sea water need further investigation as does drainage under brackish conditions to see if the non-toxic pseudo 'cat' clays, noted in para 19, can form. Reclamation of some parts of the jungle reserve of Carey Island by this method may be possible. The area would have to be bunded and drained and the salt water passed in and out through tidal gates, possibly in a system in which alternate gates are reversed. Considerable expense will be involved in these investigations but even a very modest increase of say one ton of fruit per acre on the 4,500 acres of affected soils would be worth $450,000, a sum much in excess of that needed for the investigations.

49. Finally there is the possibility of alternative uses of these soils. In temperate countries the usual system is to retain a high water-table and grow shallow rooted crops e.g. grass. This is unlikely to be feasible in Malaya. At various times rice has been planted on these soils but yields are always low. The reason for this is not fully understood since it is not a question of acidity for the pH rises considerably on water-logging. Hydrogen sulphide toxicity may be involved; the very low fertility of such soils is a contributory factor. Experiments at the

Tropical Fish Culture Research Institute, Malacca have shown that by controlling the pH of water in the ponds in these soils by liming and by adding phosphate, very good yields of fish can be obtained. More extensive use of these soils for fish farming certainly merits very close consideration. Rubber is possibly less affected than oil palms but until more information is available I do not recommend rubber in place of oil palms on such soils.

INVESTIGATIONS ON PEAT SOILS

50. Young palms grow well on peat soils but the growth falls off as the palms get older. On these soils two nutrients in particular, potassium and copper, need investigation. Peats appear to have about the same level of potassium as inland soils on which oil palms require heavy dressings of this nutrient; it may be weakly held on the exchange complex in which case it will be easily leached. Thus frequent, fairly large dressings of muriate of potash or the use of less readily leached potassium metaphosphate may be required. In view of the low level of copper in the young palm leaf there is need of research on the optimum levels in older palms, on methods and rates of application and on total copper levels and copper fixation by different kinds of peats.

51. Since large areas of deep peat soils may be planted with oil palms some comprehensive fertilizer trials are needed. A design which would incorporate say three levels of potassium, two of nitrogen, phosphorus and magnesium and a combined trace element treatment should allow an examination of the major factors affecting the nutrition of the palms

on peat. The normal planting density may not be appropriate for deep peat and it is possible that closer planting, by inducing smaller crowns, might enable the trees to stand up better.

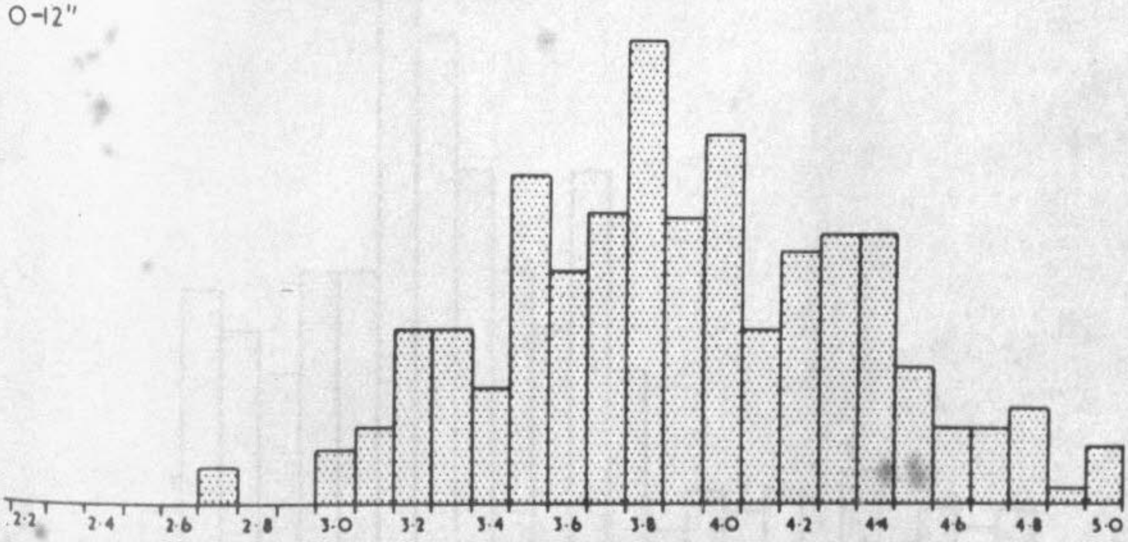
52. The best way of draining peat soils is not known but the usual method is to dig 6 ft. deep drains about three chains apart. However experience in other peats shows that the draw down, even at 10 to 12 ft., from the drain, is negligible and that drain depths below 3 ft. have virtually no influence on the draw down. Such little evidence as exists suggests that similar conditions may apply in Malayan peats and water table measurements, relatively simple to do with small diameter perforated pipes, should show the efficiency of the present drainage system.

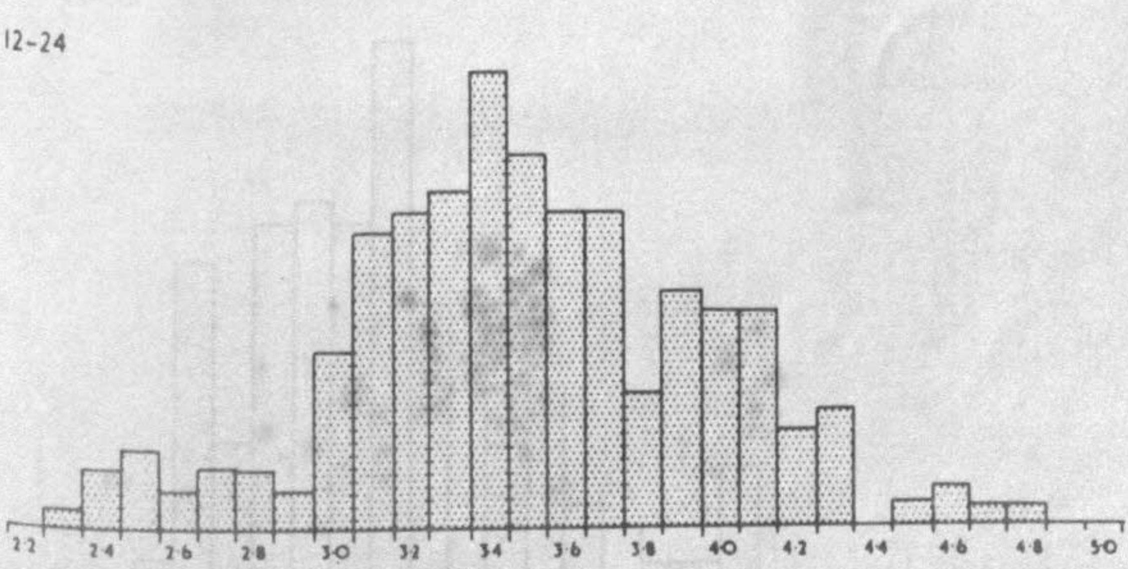
WATER CONTROL IN COASTAL CLAYS

53. It may be possible to improve still further the good oil palm yields on coastal clays by better water control, particularly by additional supplies during dry spells. Although irrigation may be considered uneconomic there is no evidence to support this and none will be available until irrigation trials are done. On an experimental basis a sprinkler system would be the most convenient but on a commercial basis some system of using the drains as irrigation channels, as is done for sugar cane in British Guiana, would have to be evolved. Before experimental work on irrigation is done it would be of value to have more studies on water balance in the coastal clays. These would involve water table measurements, meausrements of run off through the drains, available

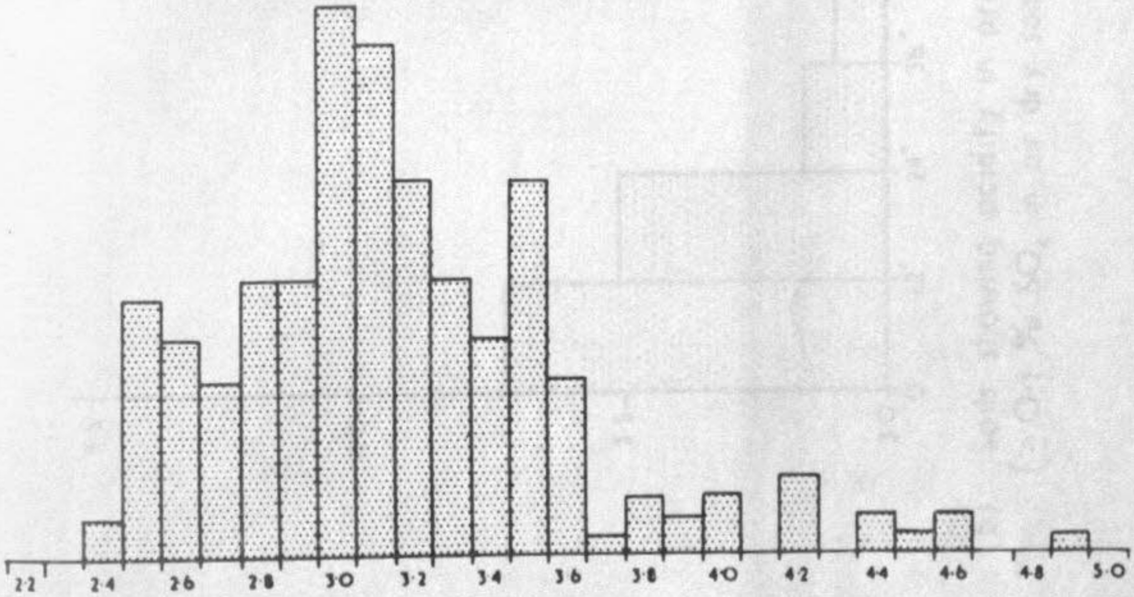
water capacity of the soil and meteorological records. Some of the estates are rather well placed for water balance studies of this nature which might be done for plantings of different ages. Experience based on trial and error is the basis of the present drainage system in the coastal estates but there are opportunities for improvement, based on studies of the influence of depth and spacing of drains in the different types of clay.

Fig. 1 Frequency distribution of pH values of air dry samples from 4 depths in acid sulphate soils (208 profiles)





24-36"


2·2
2·4
2·6
2·8
3·0
3·2
3·4
3·6
3·8
4·0
4·2
4·4
4·6
4·8
5·0

36-48"

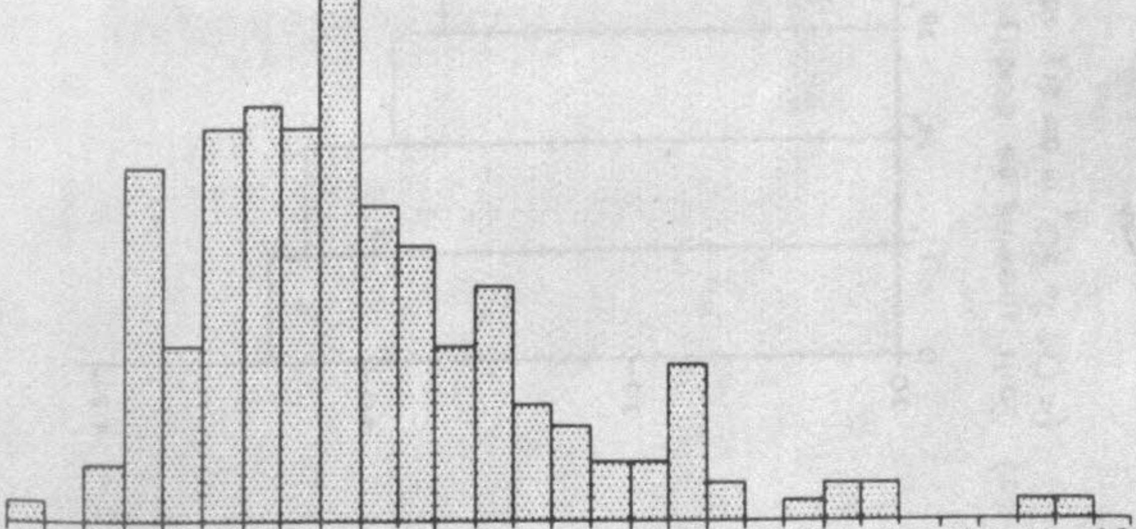
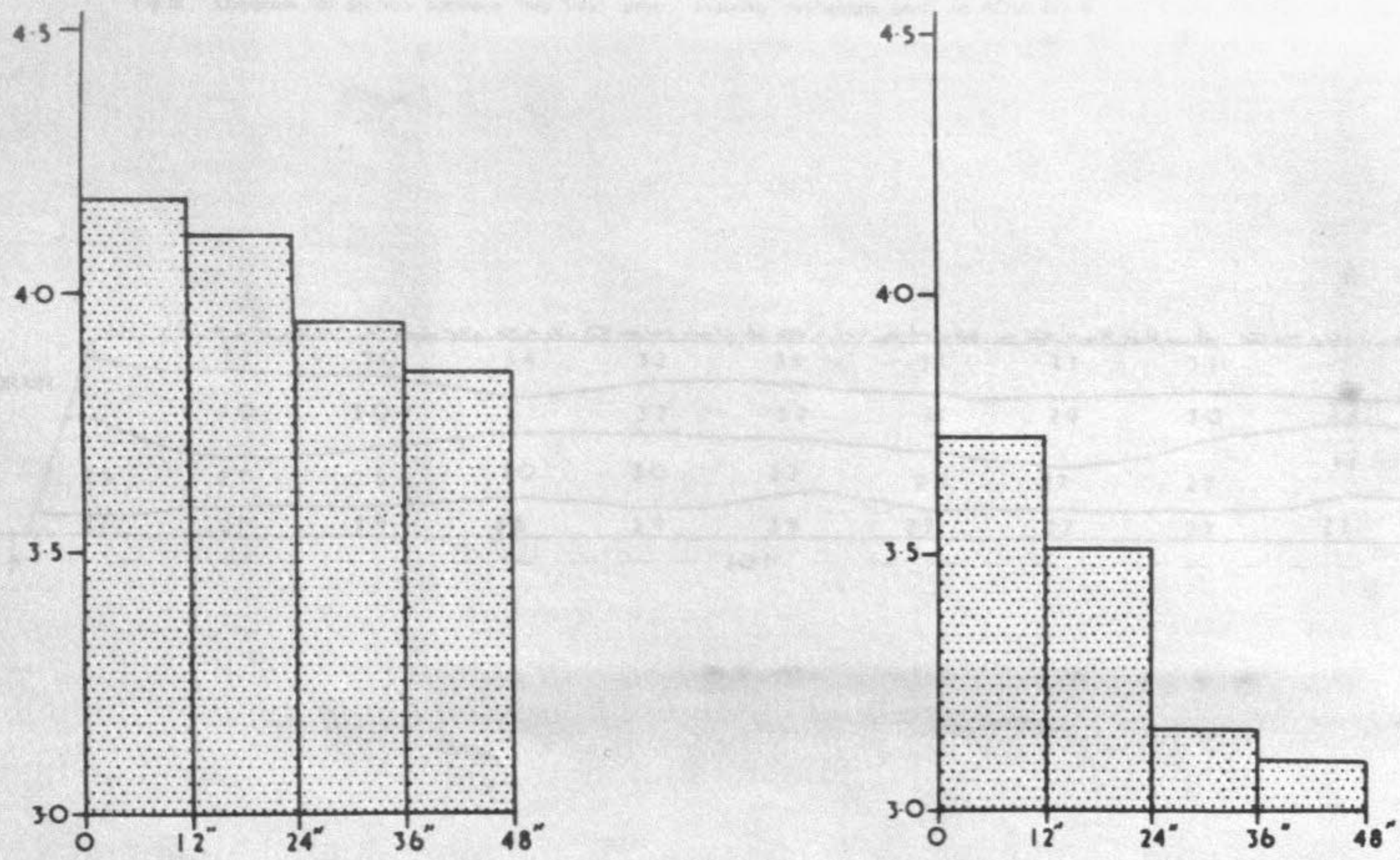

2·2
2·4
2·6
2·8
3·0
3·2
3·4
3·6
3·8
4·0
4·2
4·4
4·6
4·8
5·0

Fig. II Average pH values of air dry samples for 4 depths. (260 profiles)



(a) Soils showing no acidity in profile. (< 0·1 % SO_4 in air dry sample.)

(b) Soils showing acidity in profile. (> 0·1 % SO_4 in air dry sample.)

Fig. III Diagram of section between two field drains showing pH values (wet) to 40in depth.

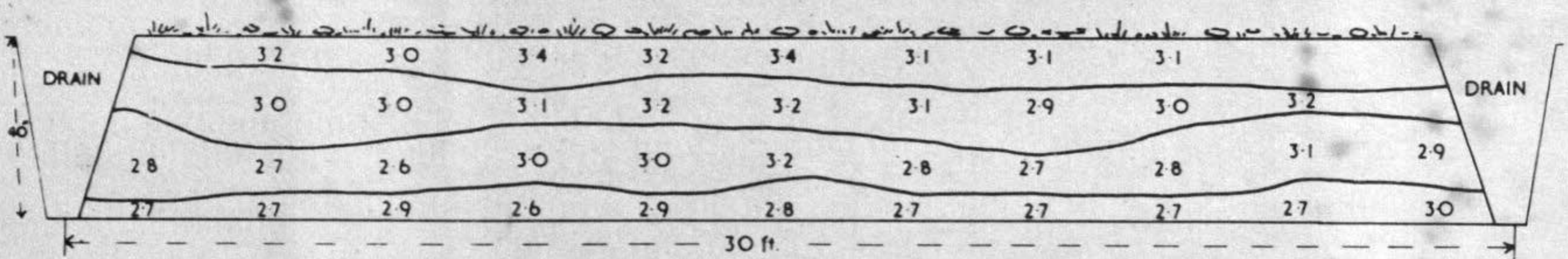


Plate I.

Poorly grown palms and almost complete absence of ground cover on an acid sulphate soil.

Plate II.

Roots of old rubber, growing in acid sulphate soil, in an area felled for replanting with oil palms.

Plate III.

Side of old field drain showing pale yellow coating of 'cat' clay on long exposed face and pale yellow mottles and blotches on freshly cleaned face.

Plate IV.

An aerial view of a coastal swamp probably similar to that in which highly sulphurous soils form.