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**A REVIEW  
OF  
LOWLAND ORGANIC SOILS  
OF  
SARAWAK**

by

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A REVIEW OF LOWLAND ORGANIC SOILS OF SARAWAK

PREFACE

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This publication presents a review of the Organic Soils of Sarawak. Organic Soils cover an extensive area in the coastal lowlands of Sarawak. This land resource is at present largely untapped for agriculture. However, future agricultural development will probably extend into areas with these soils when the very limited suitable upland areas have been adequately utilised.

Various aspects of Organic Soils had been discussed in previous departmental publications and technical papers presented at Sago Symposium (1976), Seminar on Water Management for Agricultural Development (1977), and Research Officers' Annual Conference (1977). This paper aims to compile all the information available locally and relevant information from other parts of the world into a single publication which can serve as an easy reference for all those who are interested in Organic Soils of Sarawak. It will be particularly useful to the field staff and extension workers who are serving in areas where this soil type abounds.

The purpose of this paper is to review some of the work done on tropical lowland organic soils with particular reference to Sarawak and to suggest further lines of investigation.

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"Peat" has been technically defined as organic soil that is at least 0.5 metre (1.6 feet) deep, one hectare (2.47 acres) in areal extent and with a maximum mineral content of 15 percent. Where the mineral content ranges from 15 to 65 percent, the soil is called "muck".

In Sarawak, soils with more than 50 cm of organic soil materials (more than 15 percent organic matter) are classified as peat or organic soils. Highland peats only occur in very small

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## A REVIEW OF LOWLAND ORGANIC SOILS OF SARAWAK

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Tie Yiu Liong and Kueh Hong Siong

### 1. INTRODUCTION

Organic soils of Sarawak cover an area of 1.66 million hectares (6,400 square miles) which is equivalent to 13 percent of the State's total land area. They occur extensively in the coastal lowlands.

Due to the better terrain and their proximity to the main population centres, peat areas are relatively more accessible than the mountainous interior. With the steady rise in population and the scarcity of good agricultural land in Sarawak, pressure for land has increased in recent years. Such pressure will ease a great deal if some viable plans for reclaiming the peat soils can be formulated.

Perusal of the literature reveals comparatively little information on the tropical peats. The purpose of this paper is to review some of the work done on tropical lowland organic soils with particular reference to Sarawak and to suggest further lines of investigation.

### 2. NOMENCLATURE AND CLASSIFICATION

"Peat" has been technically defined as organic soil that is at least 0.5 metre (1.6 feet) deep, one hectare (2.47 acres) in areal extent and with a maximum mineral content of 35 percent. Where the mineral content ranges from 35 to 65 percent, the soil is called "muck".

In Sarawak, soils with more than 50 cm of organic soil materials (more than 35 percent organic matter) are classified as peat or organic soils. Highland peats only occur in very small

localised areas above an altitude of 1,000 m, and for the purpose of this paper, they are not discussed any further. Classification of lowland organic soils at family, series and phase levels is based on depth of organic horizon, nature of mineral subsoil, loss on ignition, origin of organic material, and salinity (Table 1).

Peats and mucks are called Histosols under the USDA comprehensive system of soil classification (Soil Survey Staff, 1975). The main criteria for defining the Histosol are: (a) a standard minimum content of soil organic carbon; and (b) a required depth or thickness of organic soil materials. If saturated with water for prolonged periods or if artificially drained, organic soil material must have more than 12-18 percent organic carbon (21-31 percent organic matter) depending on the clay content of the mineral fraction. If the soil is almost never saturated with water, the O horizon must have more than 20 percent organic carbon (35 percent organic matter). As far as thickness is concerned, the general rule is that more than half of the upper 80 cm must be organic. On account of the temperature, moisture regime and the fibric nature of the virgin organic soils in Sarawak, most of them can be classified as Typic, Fluvaquentic or Terric Tropofibrists (Soil Survey Staff, 1975). Minor occurrences of Typic Sulfihemist are also found in the coastal marshes.

The FAO/UNESCO's (1974) system of soil classification defines Histosols as soils having an H horizon thicker than 40 cm (or 60 cm if the material consists mainly of sphagnum or moss or has a bulk density of less than 0.1g/cc) extending down from the surface or taken cumulatively within the upper 80 cm. The histic H horizon has a minimum content of organic matter ranging from 14 to 28 percent depending on the clay content. Under this system, most of the organic soils in Sarawak can be classified as Dystric Histosols, which are Histosols having a pH ( $H_2O$ , 1:5) of less than 5.5 in some part of the soil between 20 and 50 cm from the surface.

Table 1. Classification of Lowland Organic Soils in Sarawak

Depth of Organic Horizon	Nature of Subsoil	Family	Origin of Organic Layer	Loss on Ignition	Series	Salinity Phases (Groundwater EC. umhos/cm)		
						<500	500-4,000	> 4,000
50-100 cm	Non-Sulphidic, clayey (>18% clay)	MUKAH	Residual	35-65% (muck)	Epai	Epai-S1	Epai-S2	
				>65% (peat)	Mukah	Mukah-S1	Mukah-S2	
	Sulphidic, clayey (>18% clay)	MERAPOK	Residual	35-65% (muck)	Merapok	Merapok-S1	Merapok-S2	
				>65% (peat)	Patok	Patok-S1	Patok-S2	
>100 cm	Sandy (>18% clay)	IGAN	Alluvial	Undifferentiated	Mahat	Mahat-S1	Mahat-S2	
			Residual	>65% (peat)	Igan	Igan-S1	Igan-S2	
	Undifferentiated	ANDERSON*	Residual	>65% (peat)	Anderson	Anderson-S1**	Anderson-S2**	
			Alluvial	35-65% (muck)	Gadong	Gadong-S1	Gadong-S2	
				Undifferentiated	Luk	Luk-S1	Luk-S2	

\* A new series called Binio has been proposed for ANDERSON Family soils with a loss on ignition of more than 65% and having developed from vegetation of Padang Paya Swamp Forest or sedge. Anderson series would then be confined to those found under Mixed Swamp Forest.

\*\* Salinity phases follow the three depth phases e.g. And 1-S1, And 2-S2.

3. DISTRIBUTION AND OCCURRENCE OF PEAT SOILS IN SARAWAK

In Sarawak, peat soils occupy an area of 1.66 million hectares (6,400 square miles) which is equivalent to 13 percent of the State's total land area. The distribution of peat soils in Sarawak is shown in Figure 1. Shallow peats (50-100 cm), occurring at the periphery of deep peat areas, cannot be shown on the map at this scale. Deep peats (more than 1 m) are far more extensive than the shallow ones, amounting to about 89 percent of the total acreage of peat soils. The total area of peat soils, measured planimetrically from the Soil Map of Sarawak (1968), is shown for each administrative division in Table 2.

Table 2. Area (in square miles) of Peat Soils in Sarawak

Division Peat	Division							Total
	1st	2nd	3rd	4th	5th	6th	7th	
Shallow	59	219	167	110	38	110	nil	703
Deep	576	1,072	1,921	1,522	60	546	nil	5,697
Total Peat Area								6,400

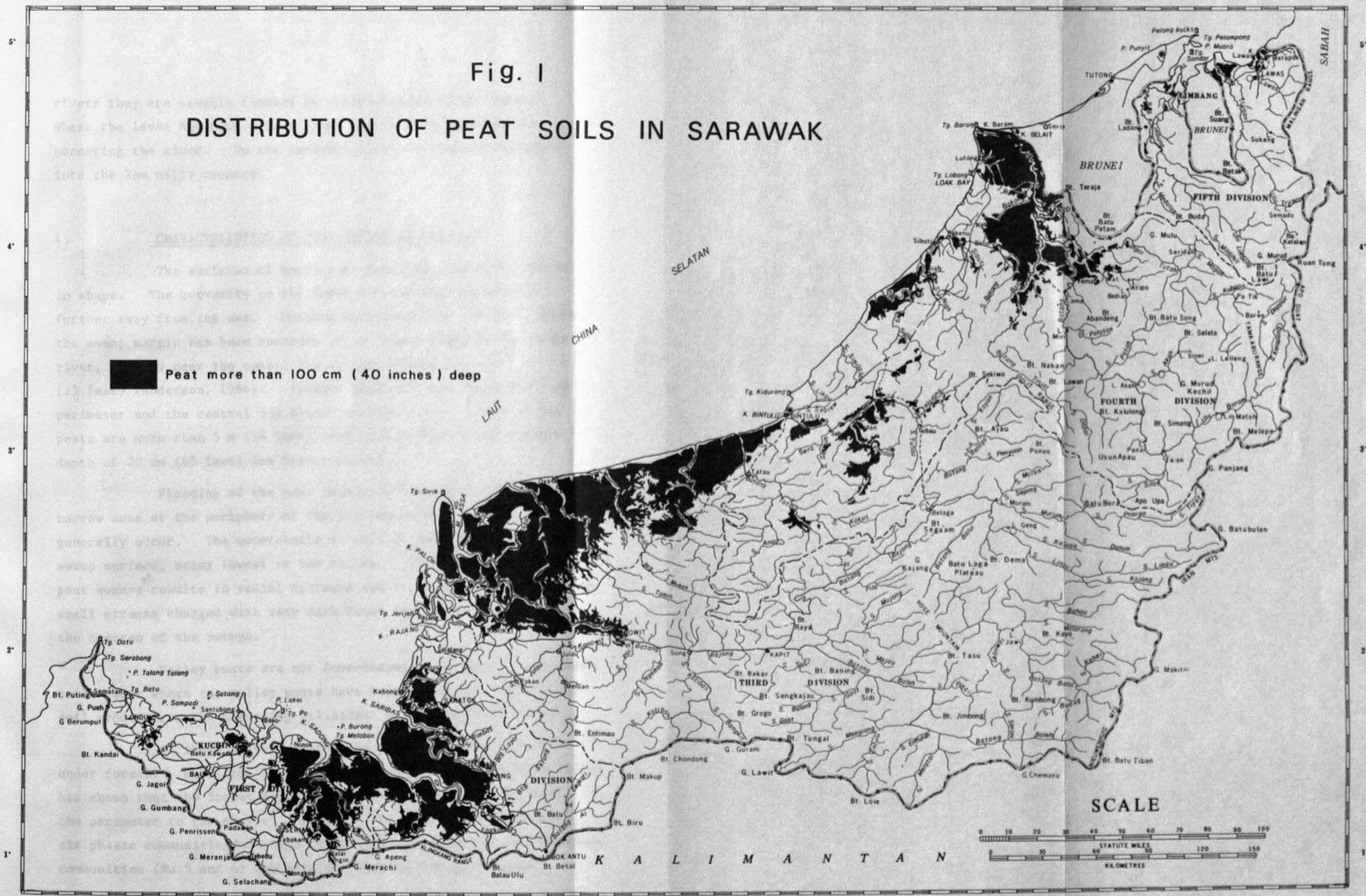
Peat soils generally occur between the lower stretches of the main river courses. Small pockets of lowland organic soils are also found in interior valleys where drainage is poor. Thus, Andriesse (1964) broadly divides lowland peats in Sarawak into basin and valley peats. Although valley peat occurs less extensively, it is cultivated more than basin peat.

Generally, basin peats are bounded by sandy ridges on the seaward side or they merge into muddy coastal flats. Along the

Fig. 1

DISTRIBUTION OF PEAT SOILS IN SARAWAK

Peat more than 100 cm (40 inches) deep



rivers they are usually flanked by a lowlying incipient levee. Where the levee has been eroded, peat can be found immediately bordering the river. On the landward side, the peats transgress into the low hilly country.

#### 4. CHARACTERISTICS OF PEAT SWAMPS IN SARAWAK

The surfaces of basin peat domes are typically convex in shape. The convexity of the domes becomes more pronounced further away from the sea. Maximum height of 15 m (49 feet) above the swamp margin has been recorded in an inland swamp up the Baram river, whereas near the coast, the maximum height is only 7 m (23 feet) (Anderson, 1964). Steeper gradients are found near the perimeter and the central bog plain is almost flat. Most of the peats are more than 5 m (16 feet) deep, and in many areas maximum depth of 20 cm (65 feet) has been recorded.

Flooding of the peat swamps is largely confined to a narrow zone at the periphery of the peat domes where muck soils generally occur. The water-table is stilted and lies close to the swamp surface, being lowest at the centre. The domed nature of the peat swamps results in radial drainage and it is not uncommon to find small streams charged with very dark brown peat water draining from the centres of the swamps.

Valley peats are not dome-shaped. In many places, muck soils occur where the valley peats have been mixed with the mineral soil eroded from the bordering hillsides or deposited by floods.

In their natural state, the peat swamps are entirely under forest. Detailed investigation of the flora by Anderson (1973) has shown that the forest types occur in a regular sequence from the perimeter to the centre. Based on the floristic composition, six phasic communities have been recognized, of which the more advanced communities (No.5 and 6) can only be found on the more highly

developed swamps. The main features that distinguish the sequence are as follows: (i) a complete or almost complete floristic change from Community 1 to 6; (ii) a decrease in the number of species per unit area; (iii) an increase in the number of individuals or stems per unit area up to Community 5; and (iv) a decrease in the average girth of a species. It is likely that the sequence represents vegetation growing under condition of decreasing fertility. The gradual impoverishment of the organic soils in the centres of the swamps can be explained by: (i) radial leaching of soluble nutrients; (ii) virtually no replacement of minerals by flood water; and (iii) decreasing levels of available nutrients in the litter of each successive plant generation (Wall, 1966; Anderson, op. cit).

#### 5. GENESIS OF LOWLAND ORGANIC SOILS IN SARAWAK

Wilford (1962) has shown by carbon dating that the lowest organic deposits in Sarawak were probably formed about 4,500 years ago when the coastline might have followed the inland margins of the present peat swamps. Genesis of Histosols depends on the accumulation of organic matter (paludization). For the organic matter to accumulate, an environment must exist such that the rate of decomposition is very much suppressed. To fulfil this condition, the most important requirement is anaerobiosis due to water-saturation for extended periods of time (Farnham and Finney, 1965). Waterlogging may be due to a high water-table or the lack of drainage as in the saucer-shaped basins impounded by impervious clay levee. Polak (1950) added that the wet condition could also be brought about by the perhumid climate and the almost constant 100 percent humidity of the air under the closed canopy of the tropical peat swamp forest. This may be an important factor for the formation of peat in the ombrogenous stage of development above the water-table.

An important factor in the accumulation of peat is the slow (or absence of) accumulation of mineral deposits. In other

words, the organic deposits have to accumulate faster in the saucer-shaped basin than the mineral deposits. Under Sarawak conditions, Andriess (1974) attributed the slow accretion of mineral matter in the basins to the small mineral loads of the rivers. He cited that the coastal plain of Bangkok, for example, is almost exclusively formed by mineral deposits because of the huge amounts of silt brought down by the Mekong River. However, with no figure of the mineral loads of the rivers quoted for the two regions, it is difficult to make valid comparison.

Adequate moisture to provide anaerobic conditions is generally necessary in every climatic zone, but Bailey (1950) postulated that an additional requirement for the formation of Histosols in the tropics is a low pH. Other factors such as microbial toxins (Mohr and van Baren, 1954), high sulphur and sodium contents (Anderson, 1964) and low nutrient status (Andriess, 1972) have been suggested. Even if these factors do play a role in paludization, they are probably of minor importance.

Based on carbon dating of organic deposits in Sarawak (Wilford, 1959), it can be calculated that the rate of paludization of the bottom layers (47 cm/century) is twice that of the surface layers (22 cm/century). Anderson (1964) attributed this to the high sulphur and sodium contents of the substratum which inhibit the microbial activity at the initial stage of development. However, not all the organic soils in Sarawak are underlain by sulphidic subsoils. More likely causes of the decrease in the rate of paludization may well be: (i) the diminishing nutrient content leading to a decline in the production of organic matter; and (ii) the better aeration leading to a higher rate of decomposition as the bog increases in elevation. In his study on the structure and development of the peat swamps of Sarawak, Anderson (op cit.) found that the almost perfect peat domes found near the coast tended to evolve to the flat-topped structure with relatively steep margins typical of advanced bogs further inland.

He accounted for this by the decrease in the rate of paludization at the centres of the bogs at a more advanced stage of development.

## 6. PHYSICAL CHARACTERISTICS

The peats in Sarawak are reddish brown to very dark brown in colour. The material is raw and woody. Well-preserved tree trunks, branches and large roots are present in abundance (Plate 1). This buried timber plays havoc with farm machinery and in the making of drains. Furthermore, it makes the land surface uneven once the peat begins to subside.

### *State of Decomposition*

The state of decomposition of the histic materials is a very important characteristic which determines many other properties of Histosols. It is evaluated by determining the fiber content or the colour of the sodium pyrophosphate extract (Soil Survey Staff, op cit.). A simple field method is to squeeze a handful of the wet organic materials: a fibric horizon emits only slightly turbid water; a hemic horizon emits turbid water and up to 2/3 of the original handful escape between the fingers; in the case of sapric material, more than 2/3 of the sample extrudes between the fingers (Buol *et al.*, 1973). Field observations show that the top few inches of organic soils in Sarawak usually consist of partially decomposed hemic materials and the subsoil is generally fibric in nature.

### *Subsidence*

A unique feature of organic soils is that they are subject to subsidence when drained. Initial subsidence is mainly caused by compaction and shrinkage due to the removal of water by free drainage and the loss of bouyancy. Subsequently, it is due to decomposition, loss of soluble organic matter through leaching, burning and wind

erosion. After the initial period following drainage, subsidence mainly depends on the depth of water-table. The most practical way of minimizing subsidence is by holding the water-table as high as the crop and field requirements will permit. Where this is insufficient, the land can be covered with a protective layer of mineral soil (Van der Elst, 1969). This not only prevents the land from sinking but also promotes better crop growth and provides a firmer surface for better land utilisation. In Sarawak, a subsidence of 60 cm (2 feet) has been recorded for a deep peat in the first two years after reclamation but subsequently with a water-table at 75-105 cm, the rate of subsidence is only about 6 cm per annum.

In addition to increasing the rate of subsidence, over-drainage can also result in irreversible drying and shrinkage. The property of irreversible drying is due to the irreversible humic colloids (Puustjärvi, 1969). The loss of water and the colloidal changes lead to considerable and irreversible shrinkage of some of the peats which would then deteriorate to a granular powder with unattractive physical and agricultural properties. Although such problem of irreversible drying would seldom be encountered under the perhumid condition in Sarawak, it may occur during an unusual drought, especially if the initial water-table is very low. The irreversibility is not as permanent as the name may suggest. A rise in water-table or prolonged flooding is able to "rewet" the soil.

#### *Bulk Density*

The very low bulk density of organic soils dictates that their water content and other physical and chemical data are best expressed on a wet volume basis (Boelter and Blake, 1964). On weight or dry volume basis, unreasonably high values are obtained, making it difficult to determine the properties of organic soils as they occur in the field or to compare the properties with those of mineral soils. To convert the conventional expressions on weight basis to wet volume basis (or vice versa), bulk density has to be determined on the basis

of wet bulk volume as obtained from the field or on saturated volume basis as undrained organic soils are continuously at or near saturation. Laboratory determination of bulk density is very simple, but taking undisturbed core samples from the field is a formidable task made more difficult by the high water-table and the tangle of roots and fallen branches. Very few bulk density determinations have been carried out with the organic soils of Sarawak. The two profiles of deep peat described by Andriesse (1972, p.314-317) have a mean bulk density of 0.12 and 0.09 g/cc at 0-30 and 60-120 cm depths respectively. Driessen and Rochimah (1976) also reported that fibric tropical forest peats have bulk density values of less than 0.1 g/cc. The bulk density value is slightly higher in the more decomposed surface soil than at some depth. The well decomposed sapric peat (with a very high loss on ignition of 95 percent or more) at Stapok Peat Research Station has an average bulk density of 0.15 and 0.13 g/cc at 0-15 and 15-30 cm depths respectively. Higher values are expected to be encountered with organic soils having higher mineral contents.

#### *Hydraulic Conductivity*

The hydraulic conductivity of the upper soil layers is the most important soil parameter in drainage problems. The hydraulic conductivity of organic soils is controlled by several factors. Within a certain peat type, the degree of humification and bulk density have the closest correlation to hydraulic conductivity and they provide good criteria for its evaluation (Martti and Radforth, 1972). The more decomposed members of organic soils have very low permeability in the order of  $10^{-4}$  to  $10^{-5}$  cm/sec which is less than that of many fine-textured mineral soils (Irwin, 1968). Soepraptohardjo and Driessen (1976) reported that some peats in Indonesia have extremely rapid horizontal hydraulic conductivity or extremely slow vertical conductivity. No hydraulic conductivity measurements have been made with the peats in Sarawak, but due to their open structure, they are expected to be very permeable.

### *Available Water*

Organic soils are commonly saturated with water. In Sarawak, they are waterlogged for most of the year round. The dome-shaped basin peats have stilted water-tables and excess water tends to drain radially from the centre. The organic materials have an extremely high water-holding capacity (WHC) both on a weight and volume basis. At field capacity, a Peninsular Malaysian peat has a moisture content of up to 88 percent (Parbery and Venkatachalam, 1964). In raw, undecomposed peat, much of the water is in the larger pores which can be drained at a very low suction of 0.1 bar (Boelter, 1964). On the other hand, a high percentage of the total porosity in the decomposed peat is largely composed of fine pores. In terms of water availability for plants, organic soils differ from mineral soils in that: (i) the volume occupied by the solid particles is much less in organic than in mineral soils; and (ii) the amount of water retained at very low tensions is much greater for organic than for mineral soils (Farnham and Finney, 1965). Highly decomposed and compacted peat has a high WHC but its permanent wilting point is also high; thus, the available water is not greatly increased when compared to mineral soils (Irwin, 1968). Because the peat has a high WHC, there is the possibility of using peat swamps as a reservoir where the peat water can be tapped for irrigating the neighbouring padi soils. The proposition certainly sounds attractive because good padi areas in Sarawak generally occur at the lower stretches of the rivers where there is a shortage of good quality water for irrigation. However, research would be required to make sure that: (i) the peat water is suitable for irrigating padi and other crops; (ii) the removal of water from the peat swamp has no drastic effect on the ecological balance of the swamps; and (iii) the swamp can yield enough water during the dry season and be recharged during the wet season. Surface water that is presently flowing out of a peat swamp should be considered the main source. Ditches to collect this surface water more quickly may be useful, but deeper drainage to increase the total recovery may result in increased subsidence and after a few years little increase in water or even a decrease.

7. CHEMICAL PROPERTIES

The recommended methods of chemical analysis used for mineral soils may not be suitable for the study of organic soils. Furthermore, the interpretation of analytical results is difficult since little work has been done on the relationship between crop performance and chemical composition of organic soils as determined by a particular method. In Sarawak, the chemical composition of organic soils is influenced to a large extent by the thickness of the organic horizon, the nature of the mineral subsoil and the frequency of flooding. In general, the older and thicker the organic horizon, the more impoverished are the surface layers (Andriessse, 1974), and if the soil is regularly flooded, it has a higher mineral content and is more fertile. Table 3 shows some of the chemical data of organic soils in Sarawak, the samples of which were collected in the course of soil survey work.

*Loss on Ignition*

By definition, histic materials have more than 21-31 percent organic matter depending on the clay content (Soil Survey Staff, 1975). In general, higher content of mineral matter corresponds to higher degree of decomposition, but other factors like flooding and cultivation can also raise the mineral content of the soils. In Sarawak, peats of Anderson Series show very high losses on ignition of 83-99 percent; shallower organic soils at the fringes of the peat swamps contain more mineral matter due to accretion from flooding (Tie and Lim, 1976). As aforementioned, valley peats generally contain more mineral matter than basin peats due to incorporation of mineral soil eroded from the bordering hillsides or deposited by floods.

*Nitrogen*

The total nitrogen content of organic soils is relatively high. In Sarawak, the total nitrogen content of organic soils is

Table 3. Chemical Properties of Major Organic Soils in Sarawak (Tie & Lim, 1976)

Analyses*	IGAN Family (Undifferentiated)				MUKAH Family/Mukah Series				ANDERSON Family/ Anderson Series	
	Peat (25-100 cm)		Mineral Subsoil		Peat (25-100 cm)		Mineral Subsoil		Peat ( 100 cm)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
pH (1:2.5, H <sub>2</sub> O)	3.8	3.3- 4.8	4.0	2.8- 5.8	3.8	3.2- 5.7	4.3	2.5- 5.3	3.4	3.1- 3.9
Loss on ignition (%)	80.6	52.4- 95.2	-	-	75.9	71.9-84.0	8.3	4.9-15.1	95.4	82.7- 98.7
Organic Carbon (%)	20.4	17.5- 33.6	1.4	0.5- 3.6	30.6	20.2-37.5	2.5	0.7- 4.4	38.4	29.8- 49.2
Total Nitrogen (%)	1.00	0.50- 2.05	0.02	0.01-0.03	1.39	0.97-2.09	0.14	0.03-0.26	1.44	1.10- 1.67
CEC (me/100g)	80.9	59.3-120.4	8.1	4.3-13.5	69.8	44.4-96.5	15.1	12.0-22.6	106.4	76.2-125.8
Exch. Ca (me/100g)	1.30	0.43- 2.91	0.66	0.31-1.64	2.00	0.53-5.28	1.60	0.26-5.25	2.62	0.71- 5.20
Exch. K (me/100g)	0.51	0.31- 0.72	0.04	Trace-0.07	0.30	0.16-0.58	0.11	0.02-0.24	0.63	0.20- 1.25
Exch. Mg (me/100g)	2.67	1.08- 4.16	0.68	0.00-1.47	2.74	1.15-6.74	1.96	0.37-4.57	4.00	0.78- 9.87
EC (umho/cm, 25°C)	-	-	-	-	196	130- 310	70	14- 175	230	160- 322
Fe (p.p.m.)	-	-	-	-	9	2- 32	3.0	1.0- 6.0	3	1- 8
Mn (p.p.m.)	-	-	-	-	19.0	6.0-49.0	17.0	4.0-39.0	13	6- 15
Zn (p.p.m.)	-	-	-	-	1.63	0.05-6.89	3.39	Trace-2.94	2.24	0.40- 4.45
Cu (p.p.m.)	-	-	-	-	0.17	0.00-0.44	0.36	0.00-0.77	Trace	Trace
Al (p.p.m.)	-	-	-	-	15	2- 25	-	-	9	5- 14

\* Organic Carbon : Walkley and Black wet oxidation method.

Total Nitrogen : Semi-micro Kjeldahl distillation method.

Exch. cations : Leaching soil with 1N amm. acetate.  
Ca and Mg determined by atomic absorption Spectrophotometer, K by flame photometer.

Fe, Mn, Cu, Zn, Al : Extracted by Morgan's solution and determined by atomic absorption spectrophotometer.

mostly greater than 1 percent. However, a large proportion of nitrogen in organic soils may be unavailable to plants as it is present in stable lignoproteins. Under the conditions in Sarawak, mineralization is expected to be very slow because of the low pH, high C/N ratio and waterlogged conditions. Kee (1970) found that liming of a Peninsular Malaysian peat greatly enhanced mineralization of organic nitrogen. In general, very acid organic soils require substantial amounts of nitrogen for satisfactory plant growth. Because of the high C/N ratio, a large fraction of the initial addition can be immobilized but this nitrogen will be released slowly later on and nitrogen requirement will decrease. Since the organic matter has a relatively high content of organic nitrogen, it is worth investigating the rate of nitrogen mineralization and immobilization after draining and liming.

### *Phosphorus*

The total phosphate content of organic soils in Sarawak generally ranges from 400 to 1,000 ppm. Wall (1966) found clear indications that in coastal swamps, phosphate levels decrease both with depth and with increasing distance inland. "Available" phosphorus shows the same trend and becomes extremely low below 60 cm. Most of the phosphate is in the organic forms and the availability of organic P may again be limited by a low microbial activity. Compared to mineral soils, organic soils have a very low phosphate fixing capacity due to the low sesquioxide and/or calcium content (Fox and Kamprath, 1971). Due to the low phosphate fixing capacity and the relatively large reserve of organic phosphorus, the availability of phosphate in organic soils is generally better than that of mineral soils. Draining and liming an organic soil may increase mineralization of organic phosphorus. The pH for optimal phosphorus availability seems to be around 5.5 (Lucas and Davis, 1961).

### *Cation Exchange Capacity*

The cation exchange capacity (CEC) of organic soils is largely due to the carboxyl groups, and to a lesser extent, phenolic and enolic groups (Coleman and Thomas, 1967). Increased humification is generally associated with increase in CEC. The CEC, being pH-dependent, increases with rise in pH. The CEC at pH 7.0 of organic soils in Sarawak usually ranges from 70 to 100 meq per 100 g soil (Table 3). Expressed on a weight basis, these high values of CEC have to be considered in the light of the low bulk density of organic soils. They have to be reduced by a factor for comparison with those of mineral soils.

### *Exchangeable cation*

Exchangeable cation status of organic soils is difficult to describe since different cations are complexed to various degree by the organic matter. Like clays, trivalent cation are more strongly adsorbed than monovalents and divalents (Kamprath and Foy, 1971), but the selectivity of peat for hydrogen ions is much greater than for the metal ions (Jungk, 1964). The exchangeable bases are readily available (Lucas and Davis, 1961). In Sarawak, organic soils generally contain less than 1 me/100 g exchangeable potassium, 0.5 - 5.0 me/100 g calcium and 1.0 - 10.0 me/100g magnesium (Tie and Lim, 1976). Even though the cation exchange capacity is high, it tends to be saturated with hydrogen ions.

### *Acidity (pH) and Liming*

All the organic soils in Sarawak are characterized by a very low pH (less than 4.0). There is a trend towards slightly higher pH values in shallow peats than in deep ones (Table 3). With such low pH, free organic acids are probably present. Some of these acids like formic, butyric and benzoic acids are toxic to plants due not only to their acidity, but also to their action as anions. Lucas and Davis

(1961) reported that organic soils have a high acidoid property and fairly acid pH values (around 5.5) even at 70 percent calcium saturation; due to these two properties and the fact that organic soils have high CEC with exchangeable calcium easily available, plants growing on organic soils can tolerate lower pH values. Soil pH depends very much on the method of determination. Farnham and Finney (1965) recommended the use of 1N potassium chloride solution and soil at field moisture conditions in the ratio of 1:1 by volume with an equilibration time of 10 minutes.

Due to the high acidity of organic soils in Sarawak, liming is essential for most crops. Because of the high buffering capacity and the low pH, large quantity of lime is usually needed. Chew and Yeong (1974) found that liming increased pH in 0-15 and 15-30 cm depths at the rate of 0.05 and 0.03 pH unit respectively for each tonne of dolomitic lime per hectare. According to Lucas and Davis (1961), the ideal pH value for organic soils is around 5.5; higher pH decreases the availability of phosphorus, manganese, boron and zinc, while very acid soils tend to be deficient in nitrogen, potassium, calcium, boron, copper and molybdenum.

#### *Trace Elements*

In a Sarawak peat, Ahmed and Ng (1973) found by extracting with 0.1N hydrochloric acid, 49 ppm iron, 43 ppm manganese, 14 ppm zinc and 1 ppm copper. Tie and Lim (1976) reported that Morgan - extractable copper is almost absent, while zinc, iron and manganese do not exceed 5, 35 and 50 ppm respectively. Extraction by Morgan's solution is used by the Peat Research institute in Finland for the determination of iron, manganese, copper and zinc (Puustjärvi, 1971). On the other hand, many workers determine the total amounts after ashing. For Sarawak peats, EDTA (1%) gave the best recovery of added copper, followed by 0.1N hydrochloric acid (Anon, 1973). However, the best methods for the assessment of plant-available copper and other

trace elements are yet to be determined. Among the trace elements, copper deficiency of crops growing on organic soils occurs most frequently. This is due partly to the very low content of copper-bearing minerals (Lucas and Davis, 1961) and partly to the strong fixation of copper by the organic matter. Copper, iron and boron deficiencies have been observed in crops growing on organic soils in Sarawak (See Section 10.3).

#### 8. MICROBIOLOGY OF ORGANIC SOILS

Some microbial activities in soil are of great importance to soil fertility. This is especially so in the case of organic soils where a large proportion of nutrient is locked up in the organic matter. As there is little or no information on the microbiology of organic soils in Sarawak, the following discussion is therefore based on overseas work. The situation in Sarawak may not be exactly the same, but the general pattern is probably similar.

In their natural state, organic soils probably have a low population of anaerobic micro-organisms tolerant to low pH. Due to the high acidity, fungi are in the majority, but actinomycetes and bacteria are also present. The population of the micro-organisms cannot be generalised because each individual organic soil varies in its chemical and consequently in its microbiological composition as well. Most of the organisms present are in a dormant or resting state, and so microbial activity in undrained peat is very slow (Küster, 1971). However, the situation is entirely altered once the organic soil is drained and cultivated. By these operations, aeration and other factors are improved. As a result, the number and the activities of micro-organisms are greatly increased (Herlihy, 1971).

Frercks and Puffs (1961) found that the decomposition of cellulose in moor soils increased with increasing degree of decomposition, rise in pH and addition of inorganic nitrogen. No nitrification takes place in peatland because no nitrifying organisms are present

in virgin peat; the mineralization of organic nitrogen can only be demonstrated after a number of years of cultivation (Herlihy, 1971) or by adding fertile garden soil (Kuster and Gardiner, 1968). Maas and Adamson (1972) also found that the rate of decomposition of raw woody peats is increased by the addition of mineral soil (an inoculum) and/or fertilizer (a source of substrate, especially nitrogen). Information is needed on the rates of mineralization and immobilization of nutrients, and on the breakdown of woody peat by the soil fauna when drainage is installed. However, the peat itself should not be looked upon as a source of nutrients (particularly N, P and K) to be released by encouraging mineralization and the destruction of the peat in the process but as a substrate to be preserved.

As aforementioned, once the organic soil is drained and limed, it becomes an ideal medium for the proliferation of a host of soil fauna and flora due to the high organic matter content. Some organisms are beneficial to the crops, but some others are pathogenic. At Stapok Station, the problem with nematode (although the subject falls outside the scope of microbiology) is particularly serious as a wide range of crops is susceptible to nematode attack (Kueh, 1972). Some crops are affected by fungal collar, root rots and white root. Bacterial wilt is also common in crops like chilli, tomato and ginger.

## 9. AGRICULTURAL POTENTIAL

Good land use has been defined as the avoidance of environmental deterioration and efficient economic utilization for a stated purpose. These two criteria are all the more important in the proper utilization of peatland as jungle removal and drainage will give rise to more drastic changes in peat than in mineral soils and the high cost of reclamation of peatland makes it increasingly more difficult to utilize this soil type economically. Some countries like the U.S.S.R. are already committed to a policy of utilizing peat deposits for fuel and industrial purposes but it is now generally

accepted that burning peat is the least efficient way of using this unique land resource. The virtue of organic soils as a growth medium both in situ and in the glasshouse is appreciated in many countries. Coulter (1957), however, suggested that peat in Peninsular Malaysia should be disposed of rapidly by removal, burning or deep drainage with the ultimate aim of using the underlying mineral subsoil for padi. On the hand, Andriess (1972) held a more moderate view that agriculture should be allowed in areas which can be permanently drained without too high cost while other deep peat areas should best be left in their natural state for silviculture. It is felt that controlled minimal drainage will allow dryland cultivation with the minimum deterioration of the peat layer, but the use of undrained peat for aquatic or semi-aquatic crops would be ideal as it combines conservation with sustained production.

Due to the extensive acreage of organic soils in Sarawak, their importance as an agricultural land resource is recognised. Moreover, their better terrain and occurrence at the more accessible coastal lowlands are in their favour. Research work in Sarawak has been started in 1966 to study the fertility and management aspects of drained peats.

#### 9.1. Present Uses of Peat

It is generally agreed that peat forms a substantial land resource in the world. Despite the fact that peat deposits, when properly developed and managed are amongst the most productive soils, vast areas of peatland still remain uncultivated. Forestry, therefore, takes up much of the present day peatlands. Peat swamps in Sarawak are a source of many species of valuable timber. However, once the peat swamp forest is logged, it may be difficult for the forest to re-establish itself. In Indonesia, Pons and Driessen (1976) rated the oligotrophic peat as suitable for protection forest but only as conditionally suitable for production forest.

The poor agronomic properties of this soil type makes it unsuitable for most agricultural crops without improvement. Sago (*Metroxylon sagu*), however, is a crop which grows successfully on unimproved peats (Plate 2). During the rubber boom years in the 1910's some 16,000 ha (40,000 acres) of peat near Sibul were drained and planted with seedling rubber. Over the many years since the peat has been drained, drastic subsidence has caused the roots to be exposed, making rubber-tapping an arduous task (Plate 3). Most of the rubber stands have leaned over and the water-table is now above the soil surface most of the time. The low yield coupled with the low rubber price makes the gardens totally uneconomic to maintain. Small acreages of 'Sarawak' and 'Mauritius' pineapple are grown for the fresh fruit market (Plate 4). Shallow coastal peats are sometimes grown with coconut. Deep peats generally cannot provide sufficient anchorage and leaning becomes a problem at a later stage although initial growth may be good (Plate 5). Pepper farmers near Sibul have grown the crop on deep peats with some success but frequently mineral soils need to be added as an improver. The main problems encountered are micro-nutrient deficiency, lodging and nematode infestation. Sibul farmers also grow vegetables quite successfully in a unique fallow-cropping system and with the use of organic and chemical fertilizers. The practice of burning the cleared vegetation on the plot plays an important role in deacidification, supply of nutrients and partially sterilizing the soil. Sometimes wood ash purchased from local charcoal kilns is used as a cheap liming material.

It is generally recognised that organic soils of Sarawak are agriculturally poorer than most mineral soils. However, where farmers have no alternative but to farm the organic soils, a range of crops can be grown. With the extreme shortage of good agricultural land in Sarawak, future agricultural development in the State may have to depend on this land resource. A classification system for evaluating the agricultural capability of organic soils has been devised (Maas *et al*, 1979). Like mineral soils, the rating of organic

soils is based on their inherent properties which have important bearings on crop performance (Appendix I). The soils are grouped into Classes O1 to O5 according to increasing severity and number of limitation affecting crop production. "O" is prefixed to all classes of organic soils in order to differentiate them from those of mineral soils. Appendix II shows the ratings of various lowland organic soils in Sarawak.

#### 9.2. Potential Crops for Undrained Organic Soils

Under undrained conditions, sago has a great degree of success in the peat swamp environment. Sago is mostly grown in the Second and Third Divisions of Sarawak on riverine levees and adjacent shallow peats. According to a planimetric measurement done in 1966, 22,700 hectares (56,000 acres) of sago are found in Sarawak.

Sago palm is water-tolerant on account of its breathing roots. Since sago can be grown under undrained conditions, all the problems associated with drainage such as subsidence and irreversible drying are avoided. It is an easy crop to establish and requires minimal maintenance and inputs. All that is required is rough clearing of the jungle before planting and occasional slashing of the secondary growth. Fertilizers are never used at present but that is not to say that addition of fertilizers would not pay under a higher level of management. The frequent flooding of the sago land probably provides the nutrients for the sago palm (Flach, 1973; Kueh, 1976). Farmers claim that sago stands can sustain reasonable yield almost indefinitely. According to Stanton(1973), some sago holdings have been in continuous production for at least 400 years. One major disadvantage of sago is its long maturity period of 15 to 20 years. Therefore, farmers must find alternative means to earn living during this long unproductive period. Intercropping with wetland crops such as cocoyams, rice and Chinese water chestnut should be examined. Research effort should also be directed towards shortening the maturity period of the sago by improved inputs, selection and breeding.

There is a great range in the yield of sago as it is affected by soil and other agronomic factors and further complicated by the fact that starch could be stored in the standing crop with little deterioration over a reasonably long period. Annual yields of 5 to 75 palms per ha (2-30 palms/acre) have been reported in Sarawak. Stanton (1973) estimated that the best sago land in Sarawak may yield 12 to 37 palms per ha per annum (5-15 palms/acre/annum). Assuming a yield of 157 kg (347 lb) of dry starch per palm (Ahmed & Sim, 1975), yields of 1.9 to 5.8 tonnes of dry starch per ha per annum can be expected. Flach (1973) reported that stands of sago planted at a spacing of 6 m x 6 m in a plantation near Batu Pahat in Peninsular Malaysia yielded 130 palms per ha per annum giving an estimated dry starch yield of 24 tonnes which is higher than any of the starch bearing root crops in the world.

Sawah rice may appear to be a promising crop for undrained peat. However, results in Indonesia and Malaysia have been disappointing as fertilized and well-managed peats (particularly those with very low mineral contents) produced rice crops with excellent vegetative growth but empty panicles. Indonesian rice farmers reported that two-thirds of the rice panicles located on deep peat are empty. From observations, Driessen and Suhardjo (1976) concluded that sterility was not caused by genetic, climatic or pathogenic factors. The sterility probably results from disturbances of the metabolism of the rice plant by factors which are pronounced under conditions of continuous inundation of deep peat. It is attributed to certain organic compounds, notably lignin degradation products and their polymers which hinder directly or indirectly, through copper fixation, essential enzyme-catalysed carbohydrate formation.

Several measures were put forward by Driessen and Suhardjo (1976) in an attempt to overcome this sterility problem. These include continuous leaching of the soil to remove noxious organic compounds and to improve oxygen supply; temporary interruption of irrigation to destroy copper-fixing compounds by oxidation; incorporation of

mineral soil; and addition of copper compounds. Soil application of copper sulphate solution ('terusi') is widely practised in Indonesia for coconut and banana. Foliar application of copper sulphate solution to wet rice was found to be better than soil application because of the high copper retention capacity of the peat. Slow-release copper sources have good prospects as well. Addition of copper sulphate to seed beds may be beneficial if the seedlings can accumulate copper in a form available for use at a later stage. Piper (1942) observed that oat seedlings grown in copper-containing solutions for a minimum of 28 days gave normal growth and yield when subsequently transplanted to copper-free nutrient solutions. It was reported in Indonesia that the rice variety 'Kwatic' is better adapted to peat areas than most other varieties. In Sarawak, local varieties like 'Merejat' and 'Empit' are also observed to perform better than others. Breeding for varieties tolerant to peat conditions may also contribute to overcoming the sterility problems.

Chinese water chestnut (*Eleocharis tuberosa*) is another potential crop for undrained peats. According to Burkill (1966) this plant belonging to the Cyperaceae family is common in marshes, swamps, and shallow lakes all over the world. In China, yields of up to 10 tonnes per ha have been recorded. It is grown like rice in fields covered with several inches of water. Tubers are eaten in China, Japan and the Philippines in salads and soups (Anon, 1952). The juice extracted from the tuber shows antibiotic activity. The sedge is sometimes used in Sumatra for matting but the mats are not durable. Water chestnut has been planted in flooded pots at Stapok and found to grow satisfactorily.

Some members of the Araceae including the genera *Colocasia*, *Xanthosoma*, *Cyrtosperma* and *Alocasia* are important tropical food crops that have potential on undrained peats as some varieties are aquatic or sub-aquatic in habit. In Hawaii, taro is grown much like rice and produces high yields under good management. *Colocasia esculenta* may yield up to 37 tonnes per ha (Purseglove, 1972) and *Xanthosoma*

*sagittifolia* some 30 tonnes per ha after 8 to 10 months growth (Campbell & Gooding, 1962). Colocasia and Cyrtosperma will probably have an important future role as complimentary crops to rice under flooded conditions to supply local food in times of emergency, or as main crops under conditions of excess salinity which does not permit successful rice culture. An important advantage of these crops is their ability to withstand injury by flooding, storms and other calamities which may destroy or greatly damage more conventional food crops.

### 9.3. Potential crops for drained organic soils

The economics of crop production is of prime importance on drained peat as it involves heavy capital outlay for reclamation. It is more problematic than mineral soils because of the changes peat undergoes upon reclamation.

Initial research work in Sarawak was aimed at screening a wide range of crops and crop cultivars that are well adapted to this unique growth medium. Experimental results over the years have given indications of the potential of annuals and short-term perennials such as ginger, essential oils, castor oil, legumes, maize, sorghum, tobacco, pineapple, sugar cane, sweet potato, tapioca, passion fruit and vegetables. Among the long-term perennials, oil palm, dwarf coconut, sago, coffee, lowland ream, cashew nut, pepper, cocoa, annatto, mulberry, clove, nutmeg and fruit trees are currently undergoing trial. Based on present knowledge it appears that the most promising crops are pineapple, tapioca, tobacco and legumes (cowpea, groundnut, soya bean and bambara groundnut). Pineapple has overall advantage over other crops as it does not require liming. Tapioca takes advantage of the excellent physical conditions of drained peat (Plate 6). Legumes in association with Rhizobia replenish the soil with nitrogen and are valuable in crop rotations, while tobacco takes advantage of the slow release of nitrogen to maintain the good quality requirement of the leaves. Sorghum, sweet potato, okra and castor oil while performing

well are often plagued by bird damage, insect pest, nematode and disease problems. For most of the long-term perennials yield results are still being collected for proper assessment. Preliminary results have indicated the potential of oil palm, coffee, annatto, and mulberry. The yield potentials of various annuals and perennials on peats in Sarawak and West Selangor are given in Table 4.

Table 4. Yield of Some Promising Crops on Peat in Sarawak and West Selangor

Botanical Name	Common Name	Yield (tonnes/ha)	
		Sarawak	West Selangor
<i>Ananas comosus</i>	Pineapple	40.0 fresh fruit	40.0 fresh fruit
<i>Manihot utilissima</i>	Tapioca	50.0 fresh tuber	49.0 fresh tuber
<i>Nicotiana tabacum</i>	Tobacco	0.7 dry leaf	1.0 dry leaf
<i>Arachis hypogea</i>	Groundnut	1.0 dry seed	3.5 fresh nuts
<i>Glycine max</i>	Soya bean	1.5 dry seed	-
<i>Vigna unguiculata</i>	Cowpea	2.1 dry seed	-
<i>Voandzeia subterranea</i>	Bambara groundnut	1.5 dry seed	-
<i>Sorghum vulgare</i>	Sorghum	1.5 dry seed	2.5 dry seed
<i>Ipomoea batatas</i>	Sweet potato	14.0 fresh tuber	24.0 fresh tuber
<i>Ricinus communis</i>	Castor oil	2.5 dry seed	-
<i>Zingiber officinale</i>	Ginger	15.0 fresh rhizome	15.0 fresh rhizome
<i>Hibiscus esculentus</i>	Okra	6.0 fresh fruit	15.0 fresh fruit
<i>Elaeis guineensis</i>	Oil palm	19.0 f.f.b. *	-
<i>Metroxylon sagu</i>	Sago	6.0 dry starch	-
<i>Coffea liberica</i>	Coffee	1.7 fresh berries	-
<i>Bixa orellana</i>	Annatto	2.0 dry seed	-
<i>Morus alba</i>	Mulberry	13.0 fresh leaf	7.5 dry leaf

\* f.f.b. = fresh fruit bunch.

## 10. RECLAMATION AND AGRICULTURAL PROBLEMS

Reclamation of peat swamps for agriculture is a formidable task which requires careful planning. The scope of preliminary investigation may well include: crop requirements; meteorological records; topographic and soil fertility surveys; water control recommendations; and economic analyses involving construction estimates and costs, maintenance recommendations and costs, total cost - benefit ratio, financing methods and marketing facilities. The general feeling now is that it is technically possible to grow crops on organic soils in Sarawak, but the capital input in overcoming the limitations may be so high that the whole venture may become uneconomical.

### 10.1. Drainage

Drainage is the major problem in the reclamation of peat swamps for agriculture. If the peat swamps can be properly drained, the organic soil itself poses less severe problems as a growth medium. Drainage is not only concerned with the removal of the excess water, but is also intimately linked with problems of subsidence and irreversible drying (see Section 6). It is necessary to remove excess water to achieve a certain degree of decomposition and to provide enough air in the soil for plant growth. However, no more water should be removed than is necessary to avoid the formation of an overdrained, unproductive soil.

The best water-table for crop production on organic soils varies with the rooting habits, stage of growth and variety of the crop, capillarity, permeability and water-holding characteristic of the soils and the distribution of rainfall over the growing season. The optimum depths of water-table for various crops under local conditions are yet to be determined. From the experience in the United States, water-table of 60 cm (24 inches) to 90 cm (36 inches) is desirable for most field crops; pasture grass will do best at shallower tables of about 45 cm (18 inches) while grains and corn may need water

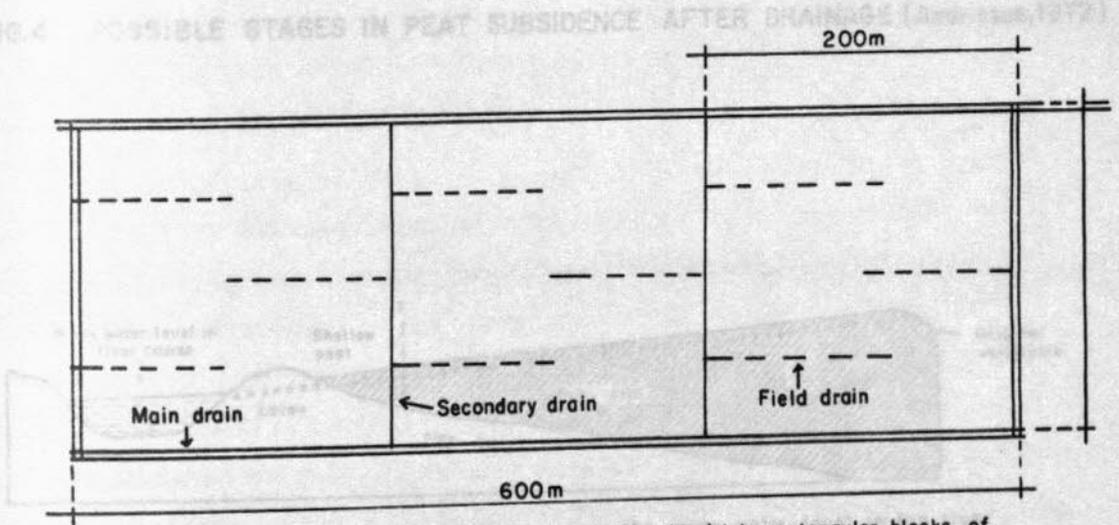
FIG. 2. DRAINAGE SYSTEM FOR RELATIVELY SHALLOW (SLIM) PEAT  
(Tay, 1969)

levels up to 100 cm (40 inches) (Stephens, 1955). The different water-table requirements point out that the problem of growing several crops on the same swamp with each crop requiring a different level of water control. Large block control is essential and crops to be grown on the same field must have similar water requirements.

As a general rule, the higher the water level can be safely held without root damage, and the more consistently it can be maintained at the same depth, the better the crop yields will be. To remove surface water quickly without overdaining the peat, Van der Elst (1969) recommended a system of main drains (0.9-1.5 m deep and 100-200 m interval) with internal ditches (0.5-0.8 m deep and 15-30 m interval) dug at right angle to the main drains. In Peninsular Malaysia, the Drainage and Irrigation Department has worked out a system for draining shallow (less than 1.5 m deep) peats and another for deep peats (Tay, 1969). The lay-outs of the two systems are shown in Figure 2 and 3 respectively. For shallow organic soils, the land is divided by main drains (1.5 m deep, 1.2 m wide) into rectangular blocks of 200 by 600 m. Within each block, secondary (1.2 m deep, 0.9 m wide) and field (0.9 m deep, 0.6 m wide) drains are constructed. For deep organic soils, a large circular drain is constructed round the land with feeder drains proceeding inwards to the centre.

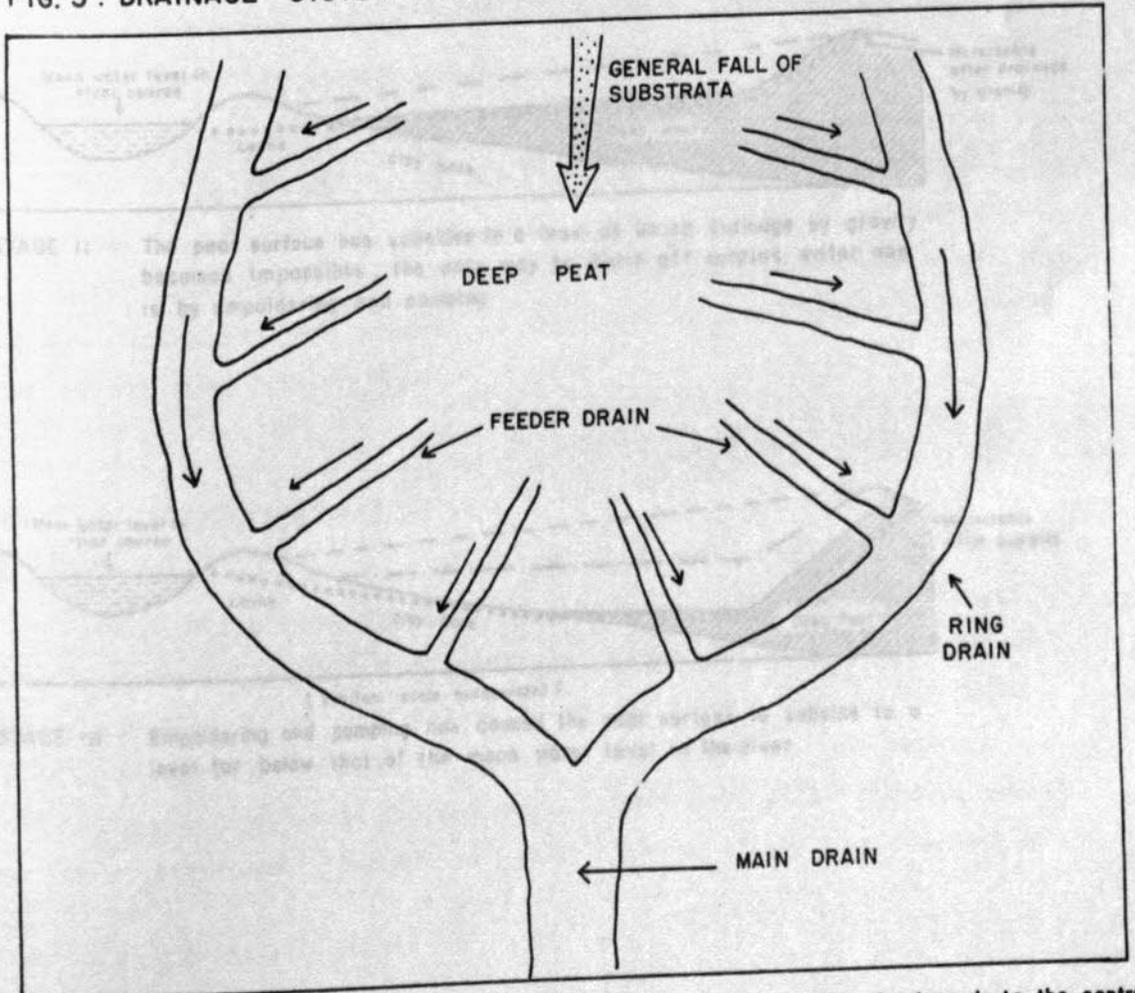
Drains have to be dug by manual labour. The removal of tree trunks and large roots is very difficult. Due to subsidence, the drainage system has to be adjusted regularly. As the land subsides, the problems of drainage and the risk of flooding will slowly increase. After the land surface has fallen to the local base level (Stage II in Fig. 4), drainage by gravity becomes impossible, and the land can no longer be used for dryland crops or costly empoldering and pumping measures need to be practised. The useful life of an organic soils for dryland crops can thus be estimated from the subsidence rate and the thickness of the peat above the main drainage channel. In order to prolong the utilization, deep rooting crops could be grown on shallow peat near the rivers whereas shallow rooting crops should be planted on deeper peat towards the centre where drains

FIG. 2 : DRAINAGE SYSTEM FOR RELATIVELY SHALLOW ( $< 1.5$  m) PEAT ( Tay, 1969 )



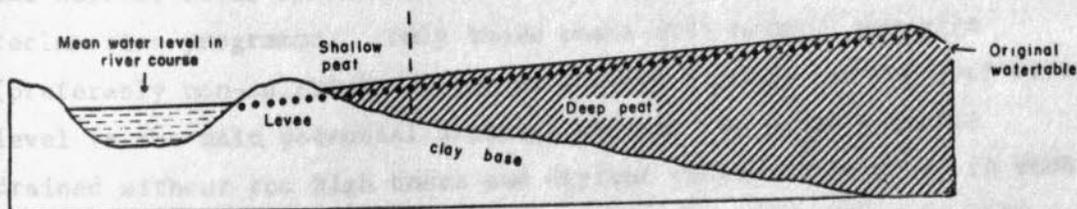
The land is divided by main drains ( 1.5 m deep, 1.2 m wide ) into rectangular blocks of 200 X 600 m. Within each block, secondary ( 1.2 m deep, 0.9 m wide ) and field ( 0.9 m deep, 0.6 m wide ) drains are constructed.

FIG. 3 : DRAINAGE SYSTEM FOR DEEP ( $> 1.5$  m) PEAT ( Tay, 1969 )

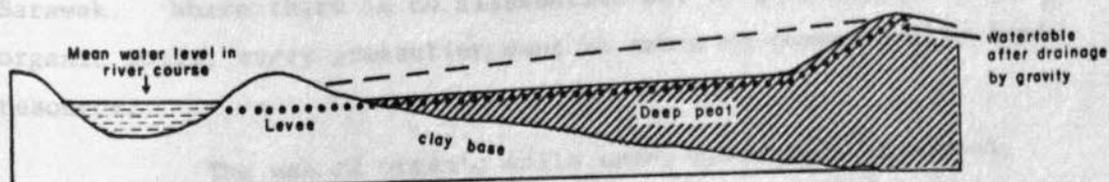


A large circular drain is constructed round the land with feeder drains proceeding inwards to the centre.

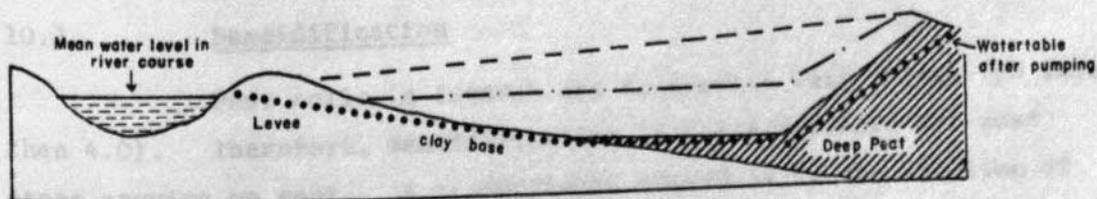
**FIG.4 : POSSIBLE STAGES IN PEAT SUBSIDENCE AFTER DRAINAGE (Andriess,1972)**



**STAGE I :** Originally, the stilted watertable is above the mean water level in the river, drainage by gravity is possible.



**STAGE II :** The peat surface has subsided to a level at which drainage by gravity becomes impossible; the only way to drain off surplus water now is by empoldering and pumping.



( Vertical scale exaggerated )

**STAGE III :** Empoldering and pumping has caused the peat surface to subside to a level far below that of the mean water level in the river

should be kept as shallow as possible. Furthermore, the normal practice of burning should be done only if absolutely necessary so that subsidence is kept to a minimum.

In view of this, local micro-relief, peat depth, bulk density, nature of underlying mineral soil and mean water level in the nearest river or streams have to be determined prior to any major reclamation programme. Only those peats with mineral subsoils (preferably non-sulphidic clays) at a level higher than the mean water level in the main potential drainage channel can be permanently drained without too high costs and dryland crops can be grown in such areas (Andriess, 1972). Any other deep peat areas are best left undistributed until such times when it would be economically justifiable to initiate reclamation. Such recommendation is ideal but it does presently rule out the agricultural use of most of the peat swamps in Sarawak. Where there is no alternative but to grow dryland crops on organic soils, every precaution must be taken to conserve this land resource.

The use of organic soils under conditions of almost continuous inundation will eliminate all the problems associated with drainage. The cultivation of sawah rice, sago, Chinese water chestnut and some members of the *Araceae* is therefore a particularly attractive proposition (see Section 9.2).

## 10.2. Deacidification

Peat soils in Sarawak are in general very acidic (pH less than 4.0). Therefore, deacidification is a prerequisite for most crops growing on peat. A conventional method is by the addition of lime which aims at raising the pH values of acidic peat to suitable levels; activating acidoids to store cation nutrients in exchangeable form; neutralising acids and acidoids formed during the growing season by the decomposition of peat; and neutralising acidic fertilizers added.

Kee (1970) in laboratory studies found that liming also induced greater mineralization of organic nitrogen in peat.

Initial work in Peninsular Malaysia and Sarawak made use of ground magnesium limestone as the liming material. The disadvantage is that this form of lime is more costly compared to ground limestone. Moreover, at the normal rate of application (7.5 tonnes/ha), it gives rise to excessive magnesium in the soil which interferes with the uptake of potassium. Wood ash containing 10.5 percent of calcium oxide has been found to be approximately one third as effective as ground magnesium limestone (30% CaO) in raising soil pH.

Liming requirement is crop specific. Sago and pineapple appear to thrive well on acid peats. For pineapple grown on Peninsular Malaysian peats, Tay & Wee (1972) found that liming depressed the mean fruit weight and increased the acid content of the fruit. Most other crops, however, require varying amounts of lime. Lim *et al.* (1973) in a pot experiment found that maize, groundnut and tapioca limed to pH 4.6 yielded significantly better than unlimed peat with pH 3.2. Chew (1971) showed that groundnut, soya bean, sweet potato and colocasia responded to 5 to 10 tonnes/ha (2 to 4 tons/acre) of ground magnesium limestone but tapioca did not. The soil pH could be maintained for at least 3½ years. In Sarawak, an application of 7.5 tonnes/ha of ground magnesium limestone would double the fresh herbage yield of napier grass (Kueh, 1972). For tapioca, 5 tonnes/ha of ground magnesium limestone raised pH from 5.7 to 6.6 and produced significantly higher yields (Anon, 1970). However, it was reported later (Anon, 1974 and 1975) that by using ground limestone, tapioca showed no response to liming up to 40 tonnes/ha (16 tons/acre) although pH was raised from 3.8 to 5.1. The anomaly could be due to the difference in the magnesium content of ground limestone (0.23% MgO) and ground magnesium limestone (15.4% MgO). Lemon grass yield was increased dramatically by micro-nutrient and liming treatments (Anon, 1973). Sweet potato grown on peat showed a significant response in vine and tuber yield to applications of up to 10 tonnes/ha of ground magnesium limestone (Anon, 1974).

The pH was raised and maintained for 3 years at 5.1. An application of 6.25 tonnes/ha (2.5 tons/acre) of ground magnesium limestone produced better growth in Robesta coffee (Anon, 1969) but the yield of berries was not significantly affected (Anon, 1972 and 1973).

It can therefore be summarised that:

- i. Pineapple and sago need no liming. On the contrary, liming can even reduce the yield of pineapple both in quantity and quality.
- ii. Tapioca generally requires no liming as well if the initial soil pH is 4.0 and above; at pH 3.5 and below, 5.0 to 7.5 tonnes/ha (2 to 3 tons/acre) of ground magnesium limestone have to be applied (Kanapathy, 1968).
- iii. For most other crops like sweet potato, maize, groundnut, soya bean, sorghum, coffee and napier grass, 5 to 10 tonnes/ha (2 to 4 tons/acre) of ground magnesium limestone are generally required.

Once the peat has been limed, 1.25 tonnes/ha (0.5 ton/acre) per year are required subsequently to maintain good growth (Kanapathy, op cit.).

### 10.3 Fertilization

The lowland peats are noted for the extremely low chemical fertility. Peat soils generally require adequate fertilization in order to become productive because of the inherent low nutrient status.

Deficiencies of macro and micronutrients in pot experiments have been reported by various workers. Joseph *et al.* (1970) using tomato as the indicator plant obtained responses to applications of nitrogen, phosphorus, potassium and boron. Ahmed & Ng (1973) using maize as the indicator plant reported responses to nitrogen, potassium,

sulphur, copper, boron and molybdenum while Lim *et al.* (1973) obtained responses to nitrogen and phosphorus for maize, groundnut and tapioca. Valid comparisons between the three experiments cannot be made because of the differences in the indicator plants used and the level of liming.

The results of pot trials have been adequately confirmed in field experiments. Various researchers have consistently obtained responses to NPK treatments. In a tobacco experiment, applications of 140 kg N, 56 kg  $P_2O_5$  and 280 kg  $K_2O$  per ha (125, 50 and 250 lb/acre respectively) increased yield significantly (Anon. 1972). For tapioca, applications of 140 kg/ha each of N and  $K_2O$  produced significant yield responses whereas  $P_2O_5$  had no effect (Anon, 1973 and 1975). Legumes responded somewhat differently. Cowpea treated with inoculant did not respond to N application while application of 112 kg per ha (100 lb/acre) of  $P_2O_5$  and 280 kg per ha of  $K_2O$  produced marked responses (Anon, 1973). In other field trials, applications of  $K_2O$  to lemon grass, napier grass and Liberica coffee have given responses while sweet potato and pineapple responded to N (Anon, 1971, 1972, 1973 and 1974).

Similar results were obtained with Peninsular Malaysian peats. In a pineapple fertilizer trial it was found that addition of N and  $K_2O$  increased yield. Fruit quality determination demonstrated that K tended to increase both sugar and acid content of the fruit (Tay *et al.* 1968). In a field trial, Chew (1970a) concluded that sweet potato on virgin Malayan peat should be given 22 to 45 kg N, 28 kg  $P_2O_5$  and 67 to 135 kg  $K_2O$  per ha and for tapioca (Chew, 1970b) 202 kg N, 56 to 67 kg  $P_2O_5$  and 123 kg  $K_2O$  per ha are required.

Copper deficiency of crops grown on peat has been identified in oil palm, sugar cane, tapioca, and coconut in Peninsular Malaysia (Kanapathy & Goh, 1969). Copper deficiency in pineapple described as 'green die-back' has been commonly encountered (Joseph *et al.* 1974). In a micronutrient study on tapioca, treatments containing no copper sulphate exhibited distinct deficiency symptoms; application of 22 to 34 kg per ha (20 to 30 lb/acre) of copper sulphate produced marked yield responses (Anon. 1974 and 1975). For maize,

Kanapathy (1972) recommended that 34 kg per ha (30 lb/acre) of copper sulphate should be added initially to be followed by 34 kg per ha (30 lb/acre) in areas where deficiency still persists. This application is expected to last 5 to 10 years as the residual effect was found to be high.

Iron deficiency has been frequently observed in a range of crops including pepper, coffee, tapioca, gramineae and legumes. This can be easily overcome by foliar sprays of ferrous sulphate solution (0.5% w/w). In a field trial, foliar applications of ferrous sulphate solution (0.5-1.5% w/w) could reduce deficiency symptoms in maize (Anon, 1972).

Boron deficiency of crops grown on peat has been reported in oil palm and Liberica coffee. Symptoms of boron deficiency in oil palm described by Rajaratnam (1972) as divergent leaf, leaf flaps, little leaf, fish-bone leaf, leaf stump, bud and heart rot have been encountered. In a micronutrient experiment on Liberica coffee using the subtractive technique, it was found that severe boron deficiency symptoms appeared in the control and minus boron treatments (Anon, 1975) (Plate 7). Soil application of sodium tetraborate could effectively eliminate boron deficiency symptoms in oil palm. Similar experiments designed to study the effect of boron and molybdenum on tapioca growth and yield did not confirm Ahmed & Ng's (1973) finding that these two elements were deficient in peat. The anomaly is probably due to a difference in sensitivity of tapioca and maize to boron and molybdenum deficiency.

Thus, it can be seen that peats are severely deficient in nitrogen, phosphorus, potassium, copper, iron and boron. These elements should be supplied to crops which are sensitive to their deficiencies. Further research should quantify the nutrient requirements of the crops more precisely. Appendix III gives some tentative fertilizer requirements of some common crops grown on organic soils in Malaysia.

#### 10.4. Mechanization and Communication Problems

Mechanization of organic soil cultivation presents several problems. Firstly, the abundance of buried timber will play havoc with the machinery. Secondly, the machinery tends to get bogged down due to the low bearing capacity of the organic soils. Therefore, large scale cultivation of organic soils is not possible until a solution has been found for the problem of mechanization.

The cost of building and maintaining roads in the peat swamp area is very high. Large amounts of fill have to be used to obtain a firm foundation, and this fill may impede drainage in the adjacent areas and cause displacement of the organic materials upward and sideways. A feasible alternative is the construction of narrow-gauge railway tracks as used by local lumberers. Wooden rafts piled with earth can also be used in some cases.

#### 10.5. Pest Problems

Experience from field trials in Sarawak has shown that soil-borne pests and diseases will constitute a problem in the utilization of organic soils for cropping. In their natural state, organic soils can only support a low population of anaerobic micro-organisms tolerant to high acidity. But once the soil is drained and limed, it becomes an ideal medium for the proliferation of a host of soil fauna and flora due to the high organic matter content. A wide range of crops is susceptible to serious nematode attack (Kueh, 1972). Some crops are affected by fungal collar, root rots and white root. Bacterial wilt is also common in crops like chilli, tomato and ginger (Kueh, op cit.).

Heavy weed infestation is also common with intensive cultivation of organic soils. Wee (1972) found that weed infestation of peat areas under pineapple cultivation in Peninsular Malaysia could result in 20 to 40 percent decrease in the fruit yield. Though weeds can be quite easily controlled by weedicides, greater cost is generally incurred with organic soils as compared to mineral soils (Burke and

O'hare, 1962). Pre-emergent herbicides are especially effective but incorporated herbicides may be quickly de-activated in the peat. In Malaysia, weeding is mainly done manually; chemical control of weeds has yet to gain popularity because of the availability of cheap labour.

#### 11. PERSPECTIVES

Peat soils occupy 13 percent of the State's total land area. They occur extensively in the easily accessible lowlands. Interest in the agricultural development of organic soils stems from the following factors: (i) extensive acreage; (ii) scarcity of good agricultural land; (iii) proximity to population centres; (iv) almost flat topography; and (v) social-political factors e.g. regional population pressure, attempt to increase food production, and making land available to the landless.

Perusal of literature shows that little is known about the peat soils in Sarawak. Up to present, the Department of Agriculture does not normally recommend the agricultural utilization of peats deeper than 100 cm. However, some local farmers do have some success in using some of the deep peat areas (e.g. padi cultivation around Simanggang, and pepper and vegetables near Sibu). From the foregoing discussions, it is also clear that with proper improvement and management, organic soils can support a wide range of crops. Sago, for instance, is naturally adapted to the peat ecology and high yields can be sustained without much input or drastic soil deterioration. Under drained conditions, pineapple has been successfully cultivated. A number of other crops, especially root crops like tapioca and sweet potato also give impressive yields. Leafy crops like mulberry in Peninsular Malaysia have given the highest yield ever recorded in the world (Joseph *et al.* 1974).

Therefore, more integrated research work needs to be done urgently in order to gain a better understanding of the agricultural capability of peat soils. Detailed investigations should be carried out to determine the range of physical, biological and chemical

properties in relation to the locality, vegetation, depth of organic deposit and nature of underlying subsoil. The relationships between the crop performance and the various properties of the organic soils have to be studied. With a better understanding of the soils and the crop requirements, the agricultural capabilities of the organic soil resources in Sarawak could be more accurately evaluated. Because the mineral soil resources in Sarawak are limited in extent and accessibility, a more detailed evaluation of the potential land use capabilities of the peatlands will be required. The changes in the soil due to cropping, drainage, fertilization and liming should also be examined. Further agronomic studies are needed to elucidate the adaptability of yet untried crops, quantify the nutrient and lime requirements of promising crops, improve the cultural and crop protection methods, and evolve practical cropping system to sustain high yields within economical levels of inputs and minimal soil deterioration. Above all, the methods of reclamation and the economics of each crop must be carefully evaluated to see whether peat swamps can be economically reclaimed for agricultural utilization.

It is evident that high-value crops like vegetables play an important role in peat utilization in view of the high cost of reclamation. The major problem in the reclamation of peat swamps for dryland crops is drainage. Ideally only those peats underlain by mineral subsoils at a level above the mean water level in the main drainage channel could be permanently drained for dryland agriculture. In case of other deep peats, continual subsidence will eventually make drainage by gravity impossible and the land becomes useless for dryland crops unless costly measures like empoldering and pumping are practised. The use of organic soils for the cultivation of wetland crops under conditions of almost continuous inundation seems to be very attractive, but more research is also needed. Areas of deep peats may be best suited to silviculture. Research in forest crops and their management is therefore also recommended. Fish farming may be another alternative and its feasibility should also be examined.

It should be stressed that very careful planning should precede any reclamation programme. The scope of preliminary investigations may well include: crop requirements; meteorological records; soil survey; drainage recommendations; and economic analyses like construction estimates, maintenance recommendations and costs, financing methods and marketing facilities.



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The image shows a large, faint grid or table structure, possibly a map or data table. A dashed line is drawn across the top of the grid. The text within the grid is extremely faint and illegible. The grid appears to have several columns and rows, but the specific content is not discernible.

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## Limitations to Crop Suitability on Organic Soils (Maas et al, 1979)

Symbol	Type of Limitation	Degree of Limitation			
		None	Minor	Moderate	Serious
a	Depth*1 to sulphidic layer (cm)	> 100	75-100	50- 75	-
f	Fertility of the organic layer	Medium (loamy *2 muck)	-	-	Very low (peat or sandy muck)
g	Depth to groundwater-	-	-	30- 60	0-30
	natural drained			30- 60	
h	Degree of humification	Hemic-sapric	-	-	Fibric
i	Inundation hazard (frequency & duration)	None	Infrequent, short	Frequent, short	Infrequent, long
n	Nature (texture) of mineral subsoil at 50-100 cm	Fine loamy to clayey	-	-	Sandy to coarse loamy
o	Depth of organic layer (cm)	-	-	50-100	> 100
s	Salinity of groundwater (umhos/cm)	< 1,000	-	-	1,000-4,000
					> 4,000
					Frequent and long, or submerged
					-

\*1 - Depth after reclamation; allow 25 cm more for subsidence of virgin organic soils.

\*2 - The clay content of the mineral component must be greater than 18%.

APPENDIX II

Agricultural Capability Ratings of Lowland Organic Soils  
(Maas *et al.*, 1979)

Soil Series	Salinity Phases	Capability Class *1	
		Unimproved	Improved
1. Epai	Epai	03g	02
	Epai-S1	04gs	02
	Epai-S2	05gs	02
2. Mukah	Mukah, Mukah-S1	04gf	03f
	Mukah-S2	05gs	03f
3. Merapok	Merapok, Merapok-S1	04ga	03a
	Merapok-S2	05gs	03a
4. Patok	Patok	04ga	04af
	Patok-S1, Patok-S2	05gs	04af
5. Mahat	Mahat, Mahat-S1	04ga	03a
	Mahat-S2	05gs	03a
6. Igan	Igan	05gn	04nf
	Igan-S1 and Igan-S2	05gs	04nf
7. Anderson and Binio	Anderson, Anderson-S1, Binio	05go	04fo
	Anderson-S2	05gs	04fo
8. Gadong	Gadong, Gadong-S1	04go	03o
	Gadong-S2	05gs	03o
9. Luk	Luk, Luk-S1	04go	03o
	Luk-S2	05gs	03o

\*1 Most of the organic soils, particularly the shallow ones at the fringes of the peat domes, are subject to flooding. The soils have been rated on the assumption that the flood hazard is either none or minor. Therefore, a soil series may be downgraded and "i" indicated if it occurs in an area subject to moderate, severe or very severe flooding.

### APPENDIX III

#### Fertilizer Requirements of Crops Growing on Organic Soils

Although a number of crops can be grown on organic soils, it should be borne in mind that in general organic soils of Sarawak and the peats in particular need higher inputs than mineral soils. The fertilizer requirement is very specific for each crop and so it is impossible to give a blanket recommendation for each Crop Group. For most crops large quantities of lime, N, P, K, and trace elements (particularly Cu, Fe and B) have to be added. Initial fertilizer requirements for some of the crops growing on peat soils are given below:

1. Vegetables like long bean, French bean, green pepper and chilli:-  
280-560 kg/ha of N,  $P_2O_5$ ,  $K_2O$  and MgO in the ratio of 10:8:18:2;  
cucumber:- 560 kg/ha of N,  $P_2O_5$ ,  $K_2O$  and MgO in the ratio of 12:6:22:2 (Tay, 1972).
2. Soya bean, groundnut and cowpea:-  
45-78 kg/ha N and  $P_2O_5$ , 95-112 kg/ha  $K_2O$ , 5-10 tonnes/ha ground magnesium limestone (g.m.l.) plus trace elements (T.E.) like Cu and Fe (Tay, 1972; Anon. 1970-74).
3. Maize on shallow peat with 20% mineral matter:-  
180, 60, 60 and 30 kg/ha of N,  $P_2O_5$ ,  $K_2O$  and  $CuSO_4$  respectively, 6 tonnes/ha of g.m.l. (Kanapathy and Goh, 1970).
4. Tapioca:- 202, 56 and 123 kg/ha of N,  $P_2O_5$  and  $K_2O$  respectively; 5.0 - 7.5 tonnes/ha of g.m.l. if pH < 3.5; T.E. like Cu and Fe (22-35 kg/ha) (Tay, 1972).
5. Tobacco:- 140, 56 and 224 kg/ha of N,  $P_2O_5$  and  $K_2O$  respectively; 5 tonnes/ha g.m.l. some T.E. (Anon, 1972).

ILLUSTRATION

6. Pineapple:- 280-420 kg/ha of N (depending on variety), 14-28 kg/ha  $P_2O_5$ , 224-450 kg/ha  $K_2O$ . 40% of these for ratoon crops. Basal dressing of 2, 2, 34 kg/ha of  $CuSO_4$ ,  $ZnSO_4$  and lime respectively (Tay, 1972).

-----

Plate 1. Well preserved tree trunks, branches and large roots are present in soil under the plant.



Plate 2. Sugg the ratoon crop is a crop which grows successfully on unworked plots.

ILLUSTRATION



Plate 1. Well preserved tree trunks, branches and large roots are present in abundance in peat.

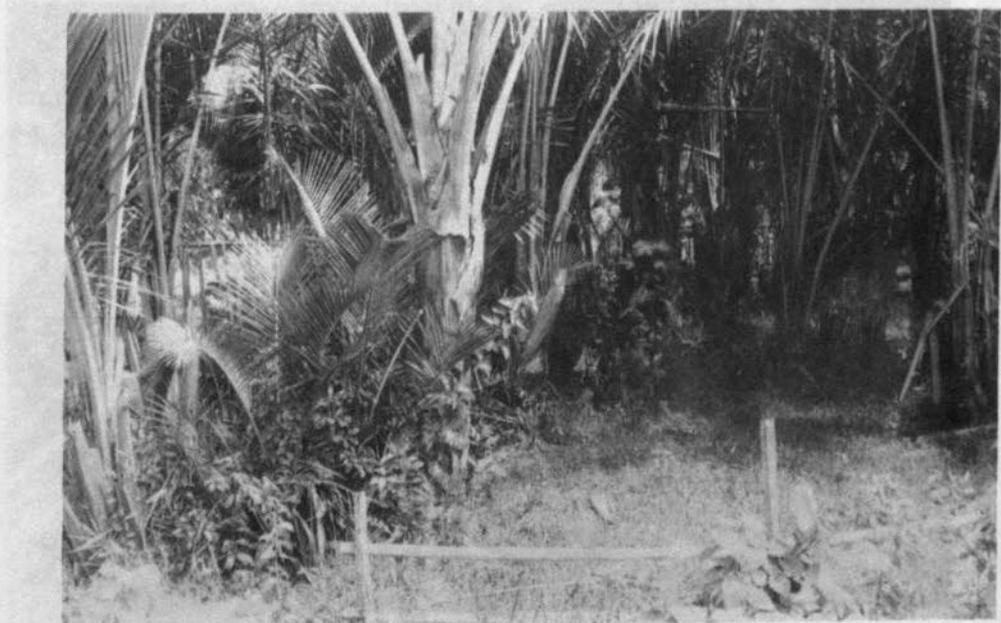


Plate 2. Sago (*Metroxylon sagu*) is a crop which grows successfully on undrained peats.



Plate 3. Evidence of severe subsidence of peat as a result of drainage in a rubber holding.



Plate 4. Small acreages of 'Sarawak' (left) and 'Mauritius' (right) pineapple are grown for the fresh fruit market.



Plate 5. A ten-year old oil palm showing severe leaning.



Plate 6. Tapioca, a root crop, takes advantage of the excellent physical conditions of drained peat.



Plate 7. Boron deficiency symptoms of liberica coffee grown on peat.



Plate 8. Well decomposed (sapric) peat at Stapok Peat Research Station.

