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Pot and Field Experiments with Maize on Acid Forest Peat from Borneo.
(Dr. B.Polak and M. Supraptohardjo).

CONT. GEN. AGRIC. RES. STATION, BOGOR (NO MAPS).
Preface

REPRINT FROM: THE SARAWAK GAZETTE, 6th AUGUST, 1949.
Sarawak's Peat Swamps. (R.W.R. Miller)

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NOTES ON THE PRIMARY VEGETATION AND SOILS OF BRUNEI

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Introduction

This paper should be termed a progress report for discussion at this Symposium rather than a paper on a completed research project. We are engaged in Brunei in a taxonomic study of the Dipterocarpaceae occurring in the State. It appeared to the author that from both a practical and academic point of view an ecological study of the family would be of great interest, and of primary importance in assessing the value of the forest resources. A three year field study in Brunei is now approaching the completion of its second year. The first year was devoted to collecting, and in the second ecological work began, helped by numerous observations over the whole area of the State Forests, which have now been more or less completely explored. A general account of findings to date follows.

Geological History and Present Geology of Brunei State

It is probable that the area now covered by Brunei State was a shallow sea in the early tertiary, and that the sands, shales, and clays deposited at this time rose above sea level towards the end of the tertiary as a peneplain.

The present geology of Brunei is due to a combination of the consequent folding, faulting, and eroding of this tertiary peneplain, and the terraces and raised beaches left by old rivers, estuaries, and the sea level changes occasioned by the glaciations.

Brunei State is politically divided into two halves. The western portion is one half of a large saucer-shaped synclinal structure, the anticline having almost entirely eroded away except on the north-western side, and the other half being beneath the sea. The whole structure is some 50 to 70 miles in diameter, and is lifted towards the south. In the centre is a range of hills, the Andulau Forest Reserve, where the strata are nearly horizontal, and the stream beds radiate from the centre in the way typical of a dissected peneplain. The eastern portion of Brunei is the drainage area of one river complex, consisting in the northern, or coastal area, of another synclinal saucer, and to the south of a complicated pattern of synclines and anticlines, rising as steep sided hills and narrow valleys from 370 to 1,900 metres in the extreme south. These latter are, except in the higher hills, mostly clays and shales, and sandstone exposures on ridges are limited in area.

Topography and Soils

The western portion, the Belait syncline, consists of the central Andulau Hills, varying between 60 and 110 metres in height, and a semicircular range of hills, the Ladan Hills, around the edge of the syncline. These former are round-topped hills, made up of a cap of yellow sands overlying clays and very soft shales. The sand has largely eroded away, filling the valleys, which are wide bottomed and flat relative to the size of the streams that drain them. Consequently there are three main types of soil here. Firstly, on the hill tops, are leached yellow sandy loams, varying in depth from a shallow covering to 2 metres. There is a thick acid humus layer on the surface, humus colouration typically in the sand to 25-30 cm., and frequently the beginning of a "Mor" formation. Where the sand is deep there are slight traces of laterisation directly above the clay, but they never become well developed. This cap often spreads down part of the hillside into the valleys. Secondly, there is a narrow belt of yellow clay soil with little undecomposed organic matter or humus on the surface. This type often occurs throughout a hill, where the sandy cap has eroded away. Lastly, the valleys, whose soils principally consist of a thick layer of acid peaty humus over badly drained undeveloped pure white sand. If over half a mile wide, the valley bottoms accumulate peat formations, while in places the peat may reach a depth of 2 metres. The hills are surrounded by the extensive peat swamps of the lower Belait and Tutong Rivers draining either side of them, and the peat swamp flora spreads up these flat sandy valleys wherever they are wide enough to allow its formation. As the streams are all small flood waters are never large and a relatively narrow valley bottom tends to develop areas of peat swamp.

The semi-circular edge of the synclinal saucer is a range of hills originating from the lifting and eroding of alternating strata of sandstone, clays and shales, strongly dipping towards the centre of the syncline, between 110 and 550 metres high. Here there are a series of narrow steep sided parallel ridges, each capped with a hard sandstone outcrop, which has broken off on the scarp slope and retreats below the clay on the dip slope. The soils therefore are either heavy yellow clays, or, on the ridges, undeveloped white sands, heavily leached and bearing a well developed "Mor" formation. In no places here do the sandstone outcrops support a deep enough soil of a large enough area to allow podsolisation to take place, and in fact along much of the hills the sandstone itself is covered with a layer of clay. Where there are outcrops the boulders are on the surface and the soil is mostly confined to the clefts between the rocks. Around the base of the hills, between them and the Andulau peneplain, are a series of small conical clay hills arising out of an extensive area of alluvial clays. These, and the peat swamps in the broad valleys leading to the sea in the north, I shall not discuss, the former as they are, or have been, virtually entirely given over to agriculture, and the second because they have already been the subject of a study by Mr. J. A. R. Anderson, and are poor in species of Dipterocarpaceae.

The coast line is sandy and the coastal successions have been much influenced by man, especially by pineapple gardeners, fishing villages, and the effects of fire.

In the eastern portion, Temburong, the hills follow the same pattern as the Ladan Hills, both in the coastal syncline and in the interior. Inland, however, sandstone outcrops are rare and hills tend to follow the harder shale strata. The high mountains of the far south however have prominent outcrops of hard sandstone, for the most part very steeply dipped. On them the thickness of the "Mor" deepens with altitude, and between 1,350 and 1,850 metres is considerably thicker than on sandstone outcrops below this level, spreading along all the well drained ridges whether they be sandstone, shale, or clay. However, a clay ridge may support 0.4 metre of "Mor" while the sandstone ridges often have peat to as much as 2 metres overlying the pure, thin horizon of undeveloped white sand derived from the parent rock.

In the valleys, the highest in Brunei being 1,600 metres, the soils remain heavy yellow clay, with little undecomposed organic matter or humus discolouration. Frequently in the more sheltered valleys the humidity is so high that I have observed a film of constantly moving water passing over the soil surface.

Though the Temburong syncline is more coastal than the Belait, the dips are less vertical and consequently there is a larger area of exposed sandstone on the ridges. On Bukit Peradayan, where the sandstone cap is only very gently dipping, the whole hilltop forms a sandstone plateau with a scarp continuing round all sides of the hill. Here, and on the edge ridge of Temburong's coastal syncline, the sandy areas are large and flat enough to allow leached white sand soil to a depth of 3 metres. A podsolised soil develops locally with an ill defined B. horizon, normally at a depth of 1—1.5 metres. Where the land is badly drained there is sometimes a poorly developed ground water podsol (also observed on badly drained sandy slopes at 1,570 metres in south Temburong). The sandstone strata which are not thick, are dissected by small valleys, which frequently cut below them, exposing the clay beneath. The valley bottoms accumulate sand eroded off the plateau. In such situations a well defined zone occurs intermediate between the clay valleys side and the undeveloped sands of the plateau. Here a deep yellow sandy loam is frequently found with a little leaching only, a mixture of clay, a thin "Mor" formation on the surface, and much humus discolouration in the first 20 cm. of the yellow sand. These are closely similar to the yellow loams of the Andulau Hills.

The estuarine muds of the river Temburong support a large mangrove forest and an area of peat swamp on the landward side.

There remains for brief discussion the soils of the raised beaches and terraces, occurring at low altitudes both at Belait and Temburong. For the most part these formations in Brunei consist of unconsolidated white sand and layers of water-eroded sandstone pebbles and gravels. The sand particle size and clay concentration has a bearing on the soil type. Some, with a high clay fraction, develop gleys in the textural B. horizon, whereas the majority bear leached white sands. The terraces and beaches are flat and often very wide. Drainage is usually poor. On medium or coarse white sand terraces the deep so-called giant podsols of the better drained areas give way to a zone of ground water podsolisation in the poorly drained centre. At the edge of the white sand terraces and raised beaches there is typically a zone of variable width where there is a deep leached yellow sandy loam of the type mentioned before.

We look forward to Dames' report on the soils of the raised beaches and terraces of the Sarawak area. Those in Brunei he has so far examined and which I have also observed are of two main types as mentioned above. The giant podsols have a well developed, matted, "Mor" formation, red-brown, and rich in roots, over a medium textured sand A1 of 10 to 25 cm. and a white medium sand A2 of great thickness. The thick dark brown or black humic podsol B. horizon can be at a depth of as much as 7 metres. In the centre of the beach drainage can be very bad and a ground water podsol type is formed. Here the "Mor" formation is thicker, less matted, less rich in roots, is frequently blackish and even slightly soupy. The A2 is much thinner than in the giant podsol, and the B. horizon is grey, diffuse, and soft. If the ground water continues to rise a thick peat formation can result and peat swamp islands occur on top of the beaches. The other type of soil on the terraces is a light grey podsolic hydromorphic soil. Here the "Mor" formation is thin, but always present, darker in colour than the giant podsol type, and well matted. The A1 and A2 are usually thin and indistinguishable from one another, while there is a B. horizon with a high clay content, pale grey, with humus or sesquioxide mottlings along the root passages. It is a textural, not a humic, podsol. This last type occurs only where the sand is fine textured, and with a high clay content. It is limited in extent in Brunei.

Correlation of Vegetation and Soils

To study the primary vegetation in Brunei two large scale enumerations, one in the Temburong Hills and one in Andulau, are being made. Besides these, belt transects and sample plots have been, or will be, made on the raised beaches and terraces, sandstone outcrops, and montane areas. As identifications of collected material has not yet begun, awaiting my return to Europe, only a general picture can be produced for discussion, with the exception of the Dipterocarpaceae.

The terraces of high clay content are limited in area, often no longer possessing primary forest, and therefore not of importance for this survey. The key to a forest survey of the area is a sound knowledge of the yellow clays, the undeveloped sandy soils bearing "Mor" formation, the podsolic soils, and the intermediate sandy loams.

Through the work of Winkler, Richards, Brown, and others the so-called Heath Forest of Borneo is widely known, though not yet, I believe, studied in detail. E.F.W.O. Brunig is at the moment making a detailed study of Heath Forests in relation to soils throughout the Sarawak area. Our concern here is only towards the Heath Forest as it occurs in Brunei. This forest type is characterised by its distinct flora, by the small height and girth of the trees, the paucity of species, and the tendency for the trees to be separated into two well defined height classes; also by the comparative rarity of climbers, the general sclerophyllous nature of the vegetation, the presence of many species with tap roots, and the occurrence of epiphytal vegetation at ground level. The general appearance is one of a forest of pole size trees, growing closely together, but providing an open canopy and a considerably higher light intensity at ground level than the typical rainforest. The Heath Forest is related both in its species and its physiognomy to the peat swamp forest. The most extreme forms of so-called "pole forest" occur in the central areas of the peat swamps, where the peat is most raised, relatively dry, and extremely poor in mineral salts. It also occurs in very badly drained centres of large raised beaches where the peat accumulation has reached a similar stage. A closely related type is found on sandstone hill plateaus where the leached sands are very shallow over the sandstone pavement.

The deep giant podsolic soils have a richer flora and a higher forest. Though they are still termed "kerangas" by the Iban and Malayas (a term which means "any land where rice will not grow, other than peat swamp"), the vegetation does not agree with the classical Heath Forest definition. *Shorea glauca*, *Agathis alba*, *Dipterocarpus borneensis*, and sometimes *Dryobalanops rappa* are abundant on these soils, and grow to great dimensions. At Badas Brunig justifiably has defined a *Dipterocarpus borneensis—Shorea glauca* association, and in places *Agathis* extends over large areas with few other trees of comparable height in the upper canopy.

This forest has its parallel on the deep leached white sands of the hilltop sandstone outcrops though they are not frequently podsolised. Here all the before-mentioned species occur, often forming a forest closely similar to the forest on the raised beaches. It should be mentioned therefore that the extreme form of pole forest is not of great economic importance, and is limited in area in Brunei, while the type just described has considerable economic possibilities not only owing to the species in the highest girth classes, but also for the fortunate tendency to gregariousness, so rare in the humid tropics.

The sandy loams, best developed and most extensive on the Andulau Hills, bear also a distinctive forest type. The general physiognomy is that of the typical primary rainforest, but there is an important Heath Forest element in the flora. This forest is outstandingly rich in species, and seems to be considerably richer than the rainforest on the heavy clay hillsides. The trees reach a girth and height equal to none other in Brunei, and the economic importance cannot be underestimated.

The rainforest borne on the clays is the widest distributed in Brunei, especially inland, as already described under soil distribution. The flora varies with drainage conditions. The clay hilltops and ridges are usually rather narrow though not as abrupt as the sandstone ridges where the dip is near the vertical. The ridges are dryer and better drained, though they are subject to greater soil humidity fluctuations, than the hillsides beneath them. The trees tend to be bigger, the flora richer, and aerial photographs as well as personal observations show that the largest crownsizes tend to be confined to the ridges. Many species in the larger girth classes are confined to the ridges, and several trees species which occur on the sandy loams are found on the ridges of the clay hills. These observations are important when considering extraction methods in this forest type.

A gradual vegetation change with altitude occurs to 1,900 metres, the highest point in Brunei, on all soils. This is complicated by considerable telescoping in different areas, apparently occasioned by the distance of the hill concerned from the coast and its height and position relative to the high mountain massifs.

Peat formations become thicker and spread over larger areas from the sandstone outcrop as altitude increases. The species show a gradual change, a continuous floral spectrum occurring from sea level to the region of 1,300 metres. Above this region the pole forest, only found here on undeveloped white sands, gives way to a stunted forest type, where trees do not usually exceed 7 to 10 metres, and moss blankets the branches and the soil frequently to great depths. This is the Elfin Woodland or Moss Forest described widely from Malaysia. In Brunei typical Moss Forest, with deep moss coverings over all the vegetation, only occurs above 1,300 metres, and exhibits another gradual floral change to the maximum height at 1,900 metres. Through this altitudinal range the general appearance and floral makeup is the same, but certain species which occurred in pole forest from sea level extend only part of the way through the moss forest, while more and more find their way in as altitude increases. It must be noted also that a forest type, florally and physiognomically closer related to the Moss Forest than the pole forest, occurs well below 1,300 metres on isolated sharply pointed sandstone peaks, but the characteristic deep moss covering is absent, and the flora is poorer than at higher altitudes. This I have recorded at 860 metres, on the isolated summit of Bukit Tanggoi, the very isolated jagged coastal ridge of Sagan at only 550 metres, and on several unnamed peaks at intermediate altitudes. I think the extreme edaphic factors combine with a micro-climate set up by the isolated and abrupt nature of the hilltop to produce the ecological conditions suitable for such a vegetation, but that the lower altitude allows greater temperatures and extremes of drought than will support a rich moss flora in such an open situation. It should be noted that there are a number of species, among the genera *Nepenthes*, *Eugenia*, *Podocarpus*, *Dacrydium* and others which occur from sea level to 1,900 metres. Hence those species recorded as being coastal and montane in distribution should not necessarily be considered as having a discontinuous distribution.

The forest on deeper undeveloped leached white sand soils remains in flora and appearance similar from sea level to 675—930 metres. Above this zone is a type, still having Dipterocarp trees, *Agathis*, and other species, but with a considerably poorer flora, and with other constituents that are confined to this height. This is typically borne on a rather thick peat, usually a reddish-rust colour, strongly matted and rooted, and relatively well drained. Above the 1,300 metres mark the vegetation type continues at least to 1,600 metres, wherever it is protected in a saddle or is at the base of a considerably higher peak. In more open conditions it gives way to a forest related to the moss forest mentioned before, but taller, richer in species, and on a thinner "Mor" formation.

In the forest of clay soils it is difficult to define definite zones. There is a noticeable floral spectrum with altitude, *Dipterocarpaceae* and other lowland families becoming rare, and *Fagaceae* and *Lauràceae* especially increasing. Above 1,400 metres the well drained ridges support a thin "Mor" formation directly over the clay, and a modified moss forest occurs, with small trees physiognomically resembling more a pole forest, less gnarled and stunted than the forests on sandstone outcrops. The flora is intermediate between the two and many species from both are absent. The hillsides and valleys bear a forest with trees with great girth and height at least to 1,650 metres.

Dipterocarpaceae in Relation to Soil Types and Altitude in Brunei

In the small State of Brunei with a total of but 938 sq. miles of Forest Reserve, there are at least 160 species of *Dipterocarpaceae*, for the most part highly specific in their ecological requirements. As the great majority of large trees are in this family, and as all forest types but the extreme pole forest and moss forest have representatives from this family, a study of their distribution relative to soils, topography, and altitude is not only vital to the economic assessment of Brunei's Forest but is also of significance for elucidation of the ecological problems involved.

A summarized survey of findings to date is best illustrated as Tables, which are included at the end of this paper, some 103 species being taken as they are better known than the others.

Arising out of the Table are the following points. Firstly, in describing the forest types floristically and assessing their economic importance it is essential to be flexible in one's judgments. Both altitudinally and edaphically the different classifications fully grade into one another and all intermediates exist. For this reason one must be guarded in generalising on the vegetation of one forest after experience of what seems to be a similar type in a different area. It should also be observed that it is difficult to describe any one species as "montane", "lowland", or "heath forest" type, and so on. Though each species has its altitudinal lim t they will seem to be wider than often claimed for them. Edaphically each species is highly specific, but the specificity does not necessarily fall in line with the vegetation types as delineated in this paper. It will also be seen that the sandy loams and well drained clay ridges are richest in Dipterocarp species. It appears in the first case that the mineral constituents of both the clay and sandstone rocks combine to provide a richer soil in the yellow sandy loams. Drainage appears to be a very important factor furthering the development of a rich Dipterocarp flora. Economically the loams are more favourable to exploitation, spreading over large areas of low undulating country, while the clay ridges are narrow, often steep and are limited areas of exceptional richness in an otherwise comparatively poor fores.

Conclusions

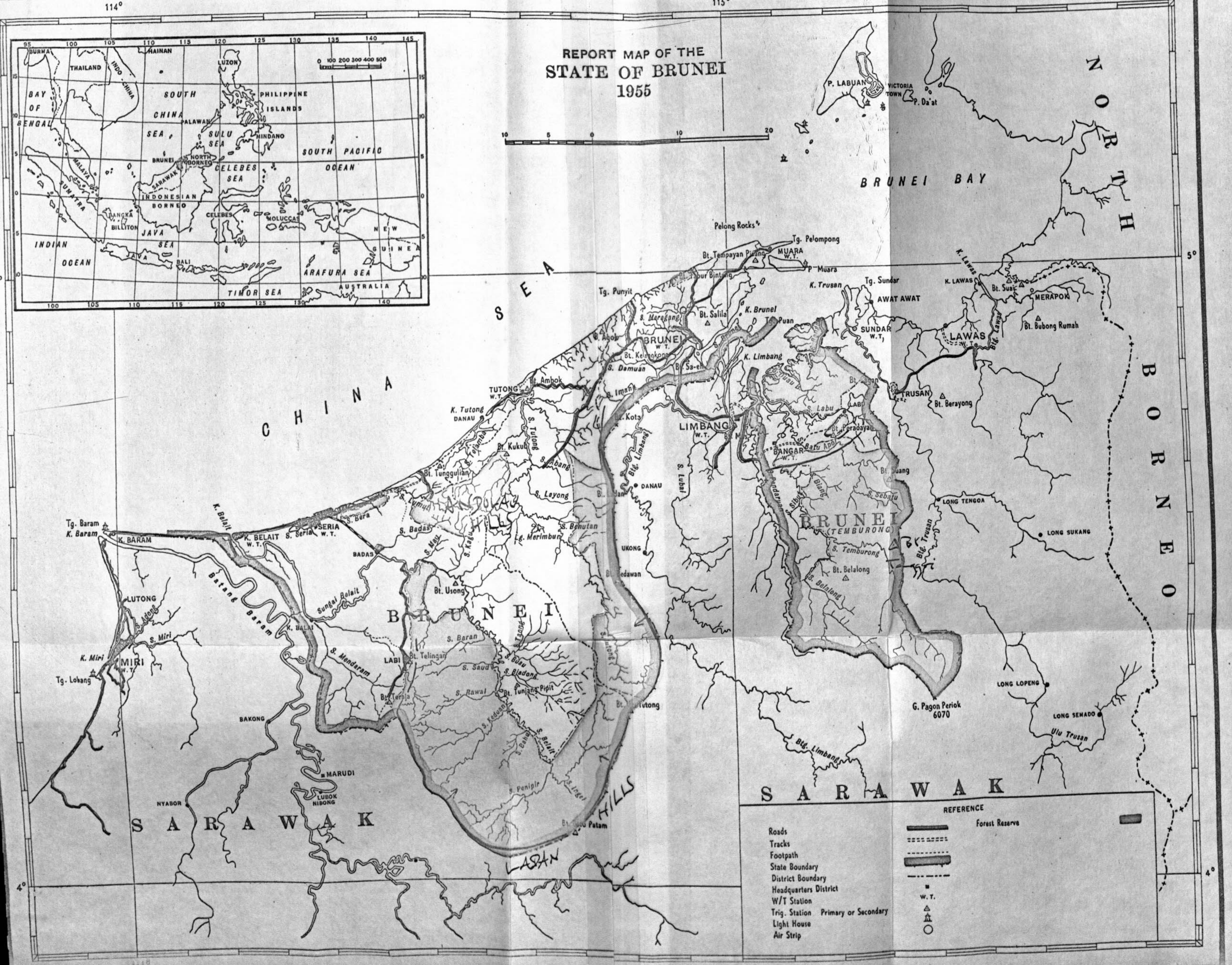
Any method of evaluating forests, and of defining forest types under the conditions prevailing on Borneo's tertiary clays, shales and sandstones, must have as its basis a good knowlegde of the soils. This we are endeavouring to do, and when the observations of three years field work are fully completed, collections examined, and information edited, we will be able to make a general assessment of the prospects of these forests. We also hope we will have gained ecological information that can guide future work throughout the area through the fuller knowledge of rainforest vegetation under these conditions. Finally, with the aid of the aerial photographic survey, we should be able with reservations to prepare a map of primary forest types throughout the State.

Biographical Note of Author

P. S. Ashton. Born in 1934. June—October 1954 took part in expedition to Lower Amazon. July 1956 Graduated at Cambridge University in Botany. January 1957 took up appointment as Forest Botanist, Brunei. November 1957 attended 9th Pacific Science Congress at Bangkok.

Work in Brunei principally research on taxonomy of the Dipterocarpaceae of the area, accompanied by ecological research and general taxonomy of timber trees. The research is carried out in the field for 3 years, followed by two in England, compiling and publishing the results.

(For discussion see page 163)


REPORT MAP OF THE
STATE OF BRUNEI
1955
SOUTH CHINA SEA
BRUNEI BAY
NORTH BORNEO
SARAWAK
BRUNEI
BRUNEI (TEMBURONG)
LIMBANG
MIRI
SERIA
TUTONG
MUARA
LAWAS
P. LABUAN
VICTORIA TOWN
REFERENCE
Roads
Tracks
Footpath
State Boundary
District Boundary
Headquarters District
W/T Station
Trig. Station Primary or Secondary
Light House
Air Strip
Forest Reserve

Semporna Peninsula, N. Borneo.
T. R. Paton.

SOIL DESCRIPTIONS

Soils Developed on Hills and Mountains

(a) *Pre-upper Eocene parent materials* - The COOK family, including the BINUANG, MADAI and COOK sub-families.

All the soils in this division are developed on slopes in excess of 30° and they are, for the most part, skeletal. There is a wide variety of soils depending on the composition of the parent material. As a result of the present reconnaissance it has been possible to map the COOK family but not the sub-families. The region is complex and the number of sub-families is not exhaustive though the main ones are differentiated.

(i) THE BINUANG SUB-FAMILY, consists of skeletal brown earths, developed on serpentine. Merutai-Binuang profile 1, at 560 chains north on the Tingkayu rentis, on a 30° slope, under high primary forest, is typical

3549	0 - 6"	Dark greyish brown 10 YR 4/2*; sandy loam; moderate, fine to medium sub-angular blocky; hard (brittle), non-sticky; much weathering serpentine; many roots merging to
3550	6 - 24"	Brown, 10 YR 4/3; clay; intersticial to serpentine.

(For analyses see I). *All soil colours are recorded in the moist state.

(ii) THE MADAI SUB-FAMILY, consists of shallow red soils, developed from resistant limestones. It is found as pockets in depressions due to karst type weathering of the limestone. The site of the type profile, Mostyn number 32, is almost flat, perhaps an acre in extent, surrounded by perpendicular limestone cliffs 50 to 100 feet high. The forest is primary but of a very stunted nature.

1183	0 - 3"	Dark reddish brown, 5 YR 3/3; clay loam; moderate, medium sub-angular to angular blocky; too wet for consistence, slightly sticky; roots common; merging to
1184	3 - 12"	Reddish brown, 5 YR 4/4; clay; poor to moderate, medium to large sub-angular blocky; too wet for consistence, slightly sticky; roots common; merging to
1185	12 - 24"	Reddish brown, 5 YR 4/4; clay; poor to moderate, medium to large (massive) sub-angular blocky; too wet for consistence, slightly sticky; many large, fresh limestone boulders; few roots. Lies abruptly on fresh limestone.

(For analyses see II).

(iii) THE COOK SUB-FAMILY, consists of light coloured yellowish-brown to reddish-yellow soils, developed from interbedded sandstones and shales. The dominant soil is one derived from sandstone though soils derived from shales do occur. The type profile is located mid-way down a long 30° slope, under primary forest, at 1600 chains on the Tingkayu rentis. It is Merutai-Binuang Profile 14.

3602	0 - 6"	Very pale brown, 10 YR 7/4; loam; moderate, fine to medium sub-angular blocky; friable, non-sticky; weathering sandstone; slightly mottled and gleyed; roots common; merging to
3603	6 - 24"	Yellow, 10 YR 7/6; sandy clay loam; intersticial to weathering sandstone; merging to
3604	24 - 36"	Slightly variecoloured, otherwise same as above.
3605	36 - 48"	Same as above.
3606	48 - 72"	Same as above.

(For analyses see III).

(b) *Miocene materials* - the MALATAI family, including the HEWETT the MANKOK and MALATAI sub-families.

All the soils in this division are developed on slopes in excess of 30° and they are, for the most part skeletal. There is a wide variety of soil depending on the type of parent material.

(i) THE HEWETT SUB-FAMILY, consist of skeletal brown earths derived from a Miocene andesitic agglomerate. The type profile is taken from just below Macpherson peak, south of mile 20 on the Baturong road, at a height of 1,300 feet, under high primary forest, on a slope of 32°.

1789	0 - 3"	Dark brown, 7.5 YR 3/2; loam; moderate to strong, medium sub-angular blocky; friable non-sticky; many roots; some rocks; merging to
1790	3 - 12"	Brown, 10 YR 5/3; clay loam; moderate, medium sub-angular blocky; sticky; abundant angular pebbles of green volcanic agglomerate; some roots, abrupt and undulating to
1791	12 - 24"	Brown, 10 YR 5/3; clay; poor, moderate to large sub-angular blocky; firm, sticky; some weathered rocks; roots common; merging to
1792	24 - 30"	Brown, 10 YR 5/3; sandy clay loam; interstitial to weathering rock.

(For analyses see IV).

(ii) THE MANKOK SUB-FAMILY, are skeletal yellowish brown soils derived from a Miocene rhyolitic tuff. A typical profile is located on the precipitous (30°+) southern slope of the hill in the Darvel Tobacco Plantations area north of the Kalumpang

0 - 2"	Dark brown, 7.5 YR 3/2; sandy loam; moderate, medium, sub-angular blocky; friable, sticky; stones common; roots common; merging to
2 - 12"	Yellowish brown, 10 YR 5/4; sandy loam; weak to moderate, medium sub-angular to angular blocky; friable, non-sticky, many rocks; few roots; merging to
12 - 18"	Yellowish brown, 10 YR 5/4; sand to sandy loam; too wet for structure or consistence, non-sticky; much weathering parent material; few roots; merging to
18 - 60"	Weathering rhyolitic tuff.

There are no analyses available for this profile. (see plate 11).

(iii) THE MALATAI SUB-FAMILY are yellowish brown skeletal soils derived from Miocene sandstones and shales. As in the Eocene materials sandstones are dominant and a typical profile can be found on the southern flank of Forbes hill in the Kalumpang valley. The slope at the site is about 30° and is under high primary jungle.

1230	0 - 1"	Dark brown, 10 YR 3/3; silty loam; granular; friable, non-sticky; many roots; abrupt and undulating to
1231	1 - 10"	Yellowish brown, 10 YR 5/4; sandy clay; moderate, medium sub-angular blocky; friable, non-sticky; many roots; merging to
1232	10 - 24"	Light yellowish brown, 10 YR 6/4; sandy clay; weak, large, angular blocky; slightly massive, but very porous and friable; some roots; merging to.
1233	24 - 36"	Weathering sandstone.

There are no analyses available for this profile.

(c) *Early Pliocene Parent Materials* - the BESAR family - including the TINAGAT, BESAR and SINON sub-families.

(i) THE TINAGAT SUB-FAMILY, are skeletal soils of brown or reddish brown colour, derived from intermediate to basic volcanic agglomerates. An example of each of the two main types will be given. The first is a reddish brown soil derived from a red tuff, from the summit of Mt. Siagil at a height of 1950 feet, on a 35° slope, under high primary jungle.

1796	0 - 12"	Reddish brown 2.5 YR 4/4; loam; moderate, medium to large sub-angular blocky; hard, non-sticky; weathering tuff common; many roots; abruptly
	12"+	Red tuff.

(For analyses see V.).

The second is derived from a basic volcanic agglomerate from the highest point of Menampili island with 20-30° slopes on either side. When the profile was described and sampled, in 1958, it had been cleared and planted to cassava, previously it was under dense *Eupatorium*.

1677	0 - 6"	Brown to dark brown, 7.5 YR 4/2; clay loam; strong, medium to large sub-angular blocky; very hard; many roots; merging to
1678	6 - 12"	Same as above but intersticial to weathering agglomerate.

(For analyses see VI).

(ii) THE BESAR SUB-FAMILY differ in some cases from the other mountain soils. They are derived from intrusive dolerite and sometimes give rise to profiles very similar to those of the Tinagat soils but within the main mountainous regions are some more gently sloping areas associated with the occurrence of these intrusive dolerites. A typical example of such an area is that found on the saddle between the Mantri and Balung valleys. The slope at the pit site is 10° overlooking 30° slopes and under high primary jungle

1749	0 - 4"	Pale brown, 10 YR 6/3; silt loam; moderate, medium sub-angular blocky; friable, sticky; many roots; merging to
1750	4 - 15"	Light yellowish brown, 10 YR 6/4; silty clay loam, moderate, medium sub-angular blocky; sticky; roots; merging to
1751	15 - 60"	Varicoloured in red (10 R 5/8), reddish yellow (5 YR 6/8) and light yellowish brown (2.5 Y 6/4); clay; moderate to strong, medium sub-angular blocky; friable, sticky; weathering dolerite; some roots; merging to
1752	60 - 72"	Dolerite weathering in neutral light grey (7/0), yellow (10 YR 8/8) and strong brown (7.5 YR 5/6).

(For analyses see VII).

(iii) SINON SUB-FAMILY are skeletal brown soils derived from intermediate intrusive rocks. On the higher parts of the hills formed from these rocks the soil is apparently non-existent. The trees root in among the boulders where a little soil material must occur. The type profile is located on Grassy Point on the south coast of Timbun Mata island. It is on a 25° slope, under a secondary growth of grass and was formerly cleared for dry padi.

1793	9 - 4"	Very dark greyish brown, 10 YR 3/2; loam; poor (massive large, sub-angular blocky; hard, non-sticky; many grass roots; merging to
1794	4 - 12"	Dark greyish brown, 10 YR 4/2; clay loam; poor (massive), large sub-angular blocky; hard (big cracks between peds); many felspars and hornblendes embedded in the peds; grass roots, many fungal mycelia, much humus staining on peds; merging to
1795	12 - 24"	Deeply weathered hornblende diorite, with humus staining extending along the common cracks.

(For analyses see VIII).

(d) *Late Pliocene Parent Materials*, - the TAJONG family, including the TAJONG, WULLERSDORG and MARIA sub-families.

All the soils in this division are developed on steep slopes mostly of about 30°. There is a wide variety of soil depending on the type of parent material.

(i) TAJONG SUB-FAMILY, derived from late Pliocene andesitic ashes. A typical profile comes from south-western flanks of Mt. Pock on a 25°-30° slope under high primary jungle.

1968	0 - 6"	Dark greyish brown 10 YR 4/2; sandy loam; moderate, medium sub-angular blocky; friable, slightly sticky; weathering rocks; roots; merging to
1969	6 - 12"	Weathering andesitic ash dominant in light yellowish brown, (10 YR 6/4)
1970-1972	12 - 72"	Same as above.

(For analyses see IX).

(ii) WULLERSDORF SUB-FAMILY, derived from rhyolitic lavas. A typical profile is found on the extremely localised flat summit of Mt. Wullersdorg surrounded by precipitous slopes at least 500 feet high. The elevation is just over 2,400 feet and the vegetation is "mossy" forest.

1739	9 - 0"	Dark reddish brown, 2.5 YR 3/4; organis matter, with abundant roots and fungal mycelia abruptly to
1740	0 - 9"	Pale brown, 10 YR 6/3; silt loam; poor (massive) structure; sticky; no roots; merging to
1741	9 - 15"	Weathered rhyolite, mainly in brownish yellow (10 YR 6/6) but also mottled (red) and gleyed (grey).

(For analyses see X).

(iii) THE MARIA SUB-FAMILY derived from dacitic lavas and ashes which contain numerous porphyritic crystals of biotite and quartz. The upper slopes of Mt. Maria are being so actively eroded that there is virtually no soil development. A typical profile has been selected from the south western flanks where the slope is 20-25° under high primary jungle

1614	0 - 6"	Mixture of dark brown (7.5 YR 3/2) and brown (7.5 YR 5/4); clay loam; moderate, medium to large sub-angular blocky; sticky; abundant quartz crystals and some weathering porphyry; many roots; merging to
1615	6 - 18"	Brown 7.5 YR 5/4; clay loam; moderate, medium to large sub-angular blocky; sticky; slightly mottled and gleyed; quartz and biotite crystals as well as weathering porphyry occur; some roots; merging to
1616	18 - 36"	Same as above but weathering porphyry increasing
1617	36 - 72"	Same as above

(For analyses see XI).

(e) *Quaternary Parent Materials* - the BOMBALAI family including the BOMBALAI and TIGER sub-families.

These soils are developed on slopes in the region of 30°, derived from Quaternary basaltic lavas.

(i) THE BOMBALAI SUB-FAMILY, consists of skeletal brown soils derived from a dark grey vesicular basalt. The type profile has been located on the crater lip of the Bombalai cone at a height of 1,700 feet, with a 30° slope to the south, under primary forest with a good leaf litter.

944	0 - 4"	Dark brown, 7.5 YR 3/2; sandy loam; moderate, medium sub-angular to angular blocky and crumb; friable, non-sticky; many quartz fragments and pebbles of vesicular basalt; roots common; worms occur; merging to

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The mountain soils of the east ridge of Mt Kinabalu

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[Plates 1 and 2]

Introduction

The region of Kinabalu provides a wide variation in four of the five main soil determining factors. The range in altitude from under 2000 ft. at the foot of the east ridge near Poring to nearly 13500 ft. at the summit of Low's Peak is responsible for wide differences in *climate,* especially in temperature, and in types of *vegetation*. Geological studies in this area (Reinhard & Wenk 1951; Collenette 1958) have shown that three very different rock types are present as *parent materials* for soil formation. These main rock types are granodiorites and allied plutonic acid igneous rocks, peridotites and related ultrabasic igneous rocks, and a series of interbedded shales and sandstones. Whilst the granodiorite forms the more elevated central core of the mountain and the other rock types outcrop on its flanks, small areas of the acid igneous rocks also occur at lower altitudes whilst both the shale-sandstone formation and the ultrabasic igneous rocks outcrop over a wide altitudinal range. Within any one altitudinal zone the soil characteristics have also been influenced by the nature of the *local relief* especially the position of the soil in relation to ridge crest, valley side or valley bottom.

Such wide variation in the pedogenetic factors in the Kinabalu area results inevitably in a diversity of soil types and in a complex soil distribution pattern. The high rainfall, however, has brought about a degree of uniformity in that nearly all the soils have been thoroughly leached of their more mobile constituents. Consequently they are generally deficient in bases and strongly acid; but even in this limited respect the leaching effect of the climate has been modified in certain topographical positions by the seepage of bases into the soil from higher lying sites. Thus it is not likely that any simple generalizations can be made about the soil characteristics, either in relation to altitude or to parent rock, that would prove to be valid for the Kinabalu area as a whole. Indeed, to the soil scientist the interest and fascination of Kinabalu is the opportunity it provides to study, in an area of undisturbed primary forest, the influence and interaction of altitude, contrasting rock type and local relief on the development and characteristics of humid tropical soils.

During the 1961 Royal Society Expedition because of the extremely difficult nature of the terrain it was only possible to examine in any detail but a small facet of the pedology of Kinabalu. The soil studies were concentrated on the long east ridge of the mountain where interbedded shales, siltstones and greywacke-type sandstones outcrop between about 1800 and 9500 ft. and thus provide a similar parent material for the soils over a range of nearly 8000 ft. At higher altitudes on this ridge the soils are developed on the granodiorite so that the soil differences cannot be attributed to changes in climate and vegetation alone but partly reflect the change in parent rock. The purpose of this paper is to outline the soil sequence on the east ridge. A more detailed account of the morphology and analyses of these soils will be published elsewhere.

Soils of the hill dipterocarp forest zone

On the east ridge typical dipterocarp forest is present up to about 4000 ft. In the upper part of this zone the soils on the ridge crests are characteristically pale yellow in colour (Munsell notation: 2·5Y 7/4 when dry) below their thin browner coloured surface horizons. There is an absence of litter layers except for a scatter of recently fallen leaves and twigs; the soil has a mull humus form. In the lower part of this forest down to about 2000 ft. the soils are similar except that they frequently have redder colours and higher clay contents in the lower soil horizons. These changes may reflect differences in soil formation but interpretation is difficult because in some cases, at least, the redder soil colour is inherited from the rock, for this geological formation includes thin strata of red coloured shales in addition to the more usual grey or cream coloured rocks.

Analyses given in table 4 show that the soils are thoroughly leached and acid. There is but a slight rise of pH with depth and base saturation is low. The organic matter is concentrated largely in the shallow mull layer and the carbon–nitrogen ratio soon falls to 10 or less.

Table 4. Chemical analyses of a soil (profile no. B7) developed on a ridge crest site in the dipterocarp forest zone

depth (cm)	pH	% base saturation	organic carbon (%)	carbon–nitrogen ratio
0–5	3·1	3	6·5	14·6
5–35	3·3	2	2·1	9·2
35–92	3·4	2	0·8	8·1
92–128	3·7	6	0·5	2·5

These soils appear similar in at least their chemical characteristics to the West African soils that Charter (Brammer 1962) has called oxysols and to the various yellow loams or earths that have been described in Brunei by Blackburn & Baker (1958) and in Sarawak by Wood & Becket (1961). Mr W. Allen, soil surveyor to the Department of Agriculture, North Borneo, informs me that such soils are very widespread on sedimentary rocks in the foothills of Kinabalu and in the adjacent Crocker Range.

On the valley sides, as distinct from the ridge crests, the soils are shallower and contain unweathered shale and sandstone fragments to the surface but otherwise are similar in their chemical characteristics to the soils of the ridge crests. The soils in the lower part of the valley sides show clear evidence of lateral seepage of bases. The analyses given in table 5 show a higher pH and a much higher base saturation than the ridge crest soils. Both pH and base saturation decrease with depth.

Morphologically the soils in the lower valley side sites differ from the soils of the higher slope and crest positions in that they have deeper and more coarsely granular mull humus horizons and their lower horizons are olive-brown rather than yellow in colour.

TABLE 5. CHEMICAL ANALYSES OF A SOIL (PROFILE NO. B3) DEVELOPED ON A LOWER VALLEY SIDE SITE IN THE DIPTEROCARP FOREST ZONE

depth (cm)	pH	% base saturation
0–5	5·4	81
5–18	5·1	87
18–70	4·7	68
70–110	4·0	34

I became particularly interested in the structural condition of the soils developed under the dipterocarp forest. The upper horizons of these soils are characterized by a highly friable consistency and by the presence of a well-developed fine-sized granular structure which is readily apparent when the soil mass is crushed under gentle pressure (figure 30, plate 1). Such a structure is characteristic of many tropical soils. It was noticed that former root channels and animal burrows in these soils are frequently partly infilled by a loose mass of fine granules which have been placed there by either ants or termites. The granules are presumably the material excavated from their galleries and nest-chambers, or they may be the collapsed remains of the framework structures that termites sometimes build to hold up wood whilst it is being eaten away. Covered runways built by termites on the exposed faces of soil pits were seen to be constructed of similar sized granules. These loose granules are of the same general size as those obtained when the coherent soil mass is crushed in the hand, and it is difficult not to think that the granular structure of the soil may have been formed, in part at least, as a result of this faunal activity, for eventually the root channels would collapse and the loose granules settle into a more coherent material. Given sufficient time a considerable proportion of the soil would be worked over in this manner and so acquire a granular structure. Nye (1955) has described how in the forest soils of West Africa termite activity has led to the formation of surface accumulations of fine sized, even *textured* material. The impression gained from examining these soils in Borneo was that the influence of termites could extend, via root runs to some depth, and that this, with subsequent colluvial movement of material down slope, would eventually result in deep layers of granular structured material especially in the lower slope positions. It is hoped that with the help of the entomologists it will be possible to examine these phenomena more closely during the second Royal Society Expedition to Kinabalu.

SOILS OF THE SCLEROPHYLLOUS MOUNTAIN FOREST ZONE

At about 4000 ft. the dipterocarp forest gives way to a mixed mountain forest which includes conifers such as *Agathis* and *Podocarpus,* and in this forest at about 4200 ft. micropodzols develop in the surface horizons on the more gently sloping sites of the ridge crests. In these soils this is a thin surface accumulation of organic matter. This *mor* type humus form is due to the non-incorporation of the litter into the mineral soil. Beneath the litter layers there is a thin pale coloured horizon, its paleness a consequence of the downward leaching of iron oxides. Below this there is a 1 cm thick horizon which is stained strong brown by the deposition of the iron oxide removed from the overlying soil material. On the steeper sites and valley sides there occur non-podzolized soils similar to the yellow earths of the lower forest.

With increasing altitude the micropodzols thicken and spread to steeper sites. By about 4750 ft. well-developed podzol-like soils occur on the ridge crests and by about 5000 ft. also occur on the steep valley sides. These soils have well-developed thick fibrous mor layers of litter accumulation and thick white coloured (Munsell notation; 2·5 Y 8/2) subsurface horizons leached of iron oxides (figure 31, plate 1). The horizons of deposition are not usually as clearly marked as in temperate podzols for the leached horizons frequently extend down as far as the weathering rock, and deposition often takes the form of successive deposits of organic matter and iron oxide on the faces of weathering shale and sandstone fragments. The absence in some of these soils of marked horizons of deposition is probably due to the high rate of erosion which would operate on such steep sites and which would restrict deep weathering and profile differentiation.

Table 6. Chemical analyses of a podzol (profile no. B 43) developed on the ridge crest at 5300 ft.

horizon	and depth (cm)	pH	% base saturation	organic carbon (%)	carbon–nitrogen ratio	'free' Fe_2O_3 %	SiO_2/R_2O_3 (< 2·0 μm)
A_{00}	0–3	2·4	n.d.	43·5	27·2	n.d.	n.d.
A_0	3–25	2·0	n.d.	40·0	25·6	n.d.	n.d.
A_1	25–36	2·8	1	2·6	16·1	< 0·1	1·33
A_2	36–46	3·2	6	0·9	6·9	< 0·1	2·48
A_2	46–54	3·3	3	0·53	4·0	0·19	2·68
B	54–79	3·5	1	0·56	4·0	5·38	1·58
B/C	79–87	3·7	1	n.d.	n.d.	1·41	1·89

Chemical analyses given in table 6 of a podzol profile developed on the ridge crest at about 5300 ft. show the marked acidity and very low base status of these soils. The organic matter is concentrated in the litter layers and has the high carbon–nitrogen ratio characteristic of podzols. Analyses of the clay fraction of the same soil, summarized by the molecular ratio of silica to the sum of alumina and iron oxide, show the leaching of sesquioxides from the pale coloured A_2 horizons and their deposition below. Determinations of the more readily extractable iron oxide (the 'free' iron oxide) content of the whole soil show the marked iron removal from the white coloured horizons (< 0·1 % Fe_2O_3) and its enrichment (> 5·0 % Fe_2O_3) in the horizon of deposition.

The development of such marked podzolization is presumably favoured by the cooler and somewhat wetter climate of these forests compared to the lower zone of non-podzolized soils. Montane tropical podzols were described by Hardon (1936) from the mountains of New Guinea and podzol-like soils were also found by Pitt-Schenkel at 6750 ft. in West Usambara, Tanganyika (Milne 1936). Mohr & Van Baren (1954) in discussing the soils of Java have emphasized the importance of temperature as a factor influencing the accumulation and humification of organic matter. They consider that 25 °C is a critical temperature below which decomposition will be slower than accumulation, that at the equator this critical temperature corresponds to about the 1000 m (3250 ft.) altitudinal line, and that at higher altitudes the organic matter content in the soil would increase and this would favour podzolization. Schuylenborgh (1958) in discussing his more recent studies of the altitudinal sequences of soils on tuffs in Java has also emphasized the importance of temperature as a factor favouring organic matter accumulation and hence podzolization. It is of interest that the high altitude (700 to 2000 m) podzolized soils that he describes lack the clear white leached horizons present in the podzols on Kinabalu, and Schuylenborgh has classified his soils as humid grey-brown podzolic and brown podzolic rather than as true podzols.

Whilst there is this association between falling temperature and accumulation of organic matter it is important to remember that the development of this zone of podzols on the east ridge of Kinabalu coincides with major changes in vegetation, especially the incoming of conifers such as *Agathis*. In New Zealand this particular genus is well known for its strong podzolizing power; very deep podzols are found to be associated with the occurrence of individual *Agathis* trees whilst Bloomfield (1953) has shown experimentally the very strong iron mobilizing power of water extracts from its leaves. Both Bloomfield (1955) and Coulson, Davies & Lewis (1960) have emphasized that it is the relatively fresh components of leaves rather than the humified organic matter that provide the active compounds for iron mobilization so that the association of podzolization with a mor humus form is likely to be coincidental rather than causal. The restriction of the micropodzols at about 4000 to 4500 ft. to the more gently sloping sites where run-off is minimal and where infiltration of leaf leachates would be especially favoured is further evidence of the importance of vegetation type and leaching as factors influencing podzolization.

Soils of the moss forest zone

Above 5500 ft. mist is prevalent and the podzol-like soils gradually give way to peaty gley soils associated with the mountain moss forest. There is no sudden increase in the mossiness of the forest. Mosses appear on the ground surface by about 4000 ft. and gradually increase in abundance until by about 6000 ft. both soil surface and tree branches are completely mantled in a thick layer of moss. The litter layer becomes thicker, less fibrous and open and changes to wet highly humified peat.

On the ridge crests there is some 40 cm of peat of a very dark reddish brown colour and with usually a fine sized granular structure (figure 32, plate 1). The mottled pale grey-brown horizons directly beneath the peat are leached of iron oxides whilst occasionally ochreous iron oxide deposits or even discontinuous iron pans are present in the lower yellowish brown horizons. In these soils it would seem that iron mobilization is to be attributed partly to the influence of gleying (i.e. the reduction of iron due to poor drainage conditions) and partly to the continued influence of podzolization. These peaty soils are mainly confined to the ridge crests, for whilst they do occur on the valley sides it is more usual to find humose mull soils in these positions. It is likely that the rapid soil creep and the increased lateral water movement are responsible for the less peaty valley sides.

The chemical analyses (table 7) of a typical peaty gley soil developed on the ridge crest at about 9200 ft. show their marked acidity, low base saturation and high carbon–nitrogen ratios to depth. The mull soils developed on the valley sides at the same altitude show (table 7) a higher pH, and a carbon–nitrogen ratio of around 10 in the surface horizon falling to 6·5 at depth.

TABLE 7. CHEMICAL ANALYSES OF TWO TYPICAL SOILS OF THE MOSS FOREST ZONE

depth (cm)	pH	% base saturation	organic carbon (%)	carbon–nitrogen ratio
(a) Peaty soil (profile no. 29) on ridge crest at 9200 ft.				
0–13	2·3	n.d.	41·0	36·8
13–50	3·1	4	29·0	25·4
50–76	3·3	2	5·7	35·6
76–100	4·5	2	2·9	23·0
(b) Non-peaty soil (profile no. 27) on valley side at 9100 ft.				
0–30	3·8	1·2	9·4	12·0
30–71	4·4	1·3	3·0	9·8
71–100	4·0	1·2	1·5	6·5

Miss Gibbs (1914) in her account of the flora of Kinabalu considered that the mossy forest owed its development to edaphic factors, for she had noted that on the Paka route on the south-west side of the mountain its occurrence coincided with the presence of 'white-sands'. These are clearly the leached A_2 horizons of the podzols or the pale grey coloured surface mineral horizons of the peaty soils. On the east ridge of Kinabalu the same rock formation is present throughout from the mossy forest down through the lowland dipterocarp forest to 2000 ft. There is no change in the geological factors which would explain the development of either the mossy forest or the associated soils, and this, together with the widespread occurrence of mossy or elfin forest at high altitudes in many other tropical areas (Richards 1957), is strong evidence that climate is the main determining factor. It is true, however, that the *upper limit* of the mossy forest on the east ridge coincides more or less with the junction between the shale sandstone formation and the granodiorite of the central massif of the mountain. Further work is needed to determine whether this is merely a coincidence on this particular ridge or a real factor influencing the upper boundary of the mossy forest. We need especially to know more of the meteorology of the mountain. Rainfall one would expect to increase with increasing altitude but only up to about 6000 to 9000 ft. Above this it would begin to fall off again as has been recorded in other tropical areas (Watts 1955). Evidence of the influence of geological factors on the boundaries of the mossy forest is clearly seen on the south-west side of Kinabalu where outcrops of ultrabasic rocks support a markedly less mossy vegetation than the adjacent outcrops of shales and sandstones. Thus it would seem likely that whilst climate is the dominant factor determining the occurrence of mossy forest the actual extent of its zone on Kinabalu may be considerably influenced by soil and other site characteristics.

High altitude soils on granodiorite

The above sequence of soil types on the east ridge, from the acid yellow earths of the dipterocarp forest through the micropodzols and podzols of the mixed sclerophyllous forest to the peaty soils of the moss forest is fairly readily explicable in terms of the decreasing temperatures, increasing rainfall and the vegetational changes associated with increasing altitude. The nature, however, of the soil types developed on the east ridge above about 9500 ft. on the outcrops of granodiorite was quite unexpected. The mossy forest gives way to a taller and markedly less mossy forest and in this respect it is interesting that Lane-Pool (Richards 1957, p. 350) also reports the occurrence of a less mossy forest with taller trees above the mistbelt of the moss forests in New Guinea. The surface accumulation of litter as peat or mor changes to a deep coarsely granular surface admixture of organic material and mineral matter. This has all the field characteristics of a mull humus form. The soils, despite their very acid nature (pH 3·5 to 4·5), contain abundant large and active earthworms (as yet unidentified) which by their continual incorporation of the litter into the soil prevent the development of surface litter layers. The earthworms frequently form large castings some 15 to 20 cm high.

Table 8. Typical chemical analyses of ranker soils developed on granodiorite at about 10000 ft.

profile no.	depth (cm)	pH	% base saturation	organic carbon (%)	carbon–nitrogen ratio
B 8	0–25	3·6	8	15·1	21·2
B 13	0–18	3·4	4	29·9	26·0

On the steep slopes there occurs on the granodiorite shallow, bouldery soils consisting of a single granular mull-like horizon over rock slabs (figure 33, plate 2). The soils have a very dark reddish brown to almost black colour due to their high organic matter content. The highly granular nature of the soil is seen clearly in figure 34, plate 2. Thin sections of the soils reveal a typical spongy mull fabric with the mineral grains included within the fine matrix. Analyses (table 8) of these soils show their marked acidity, low base saturation, high organic matter content and high carbon–nitrogen ratios.

These shallow soils appear similar in form to the rankers of Kubiena (1953) and to alpine humus soils except that the latter usually occur under grassland. The abundance and activity of the earthworms under such acid conditions, whilst surprising in relation to the occurrence of temperate lowland earthworms, is by no means unique. Costin, Hallsworth & Woof (1952) report large and active

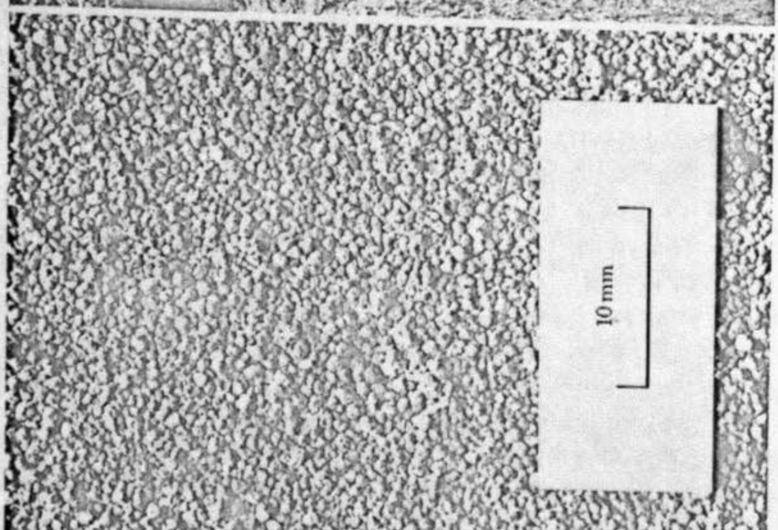

FIGURE 30. Small granular structures present infilling a former root channel at 40 to 50 cm from the surface in a soil under dipterocarp forest at 3200 ft.

FIGURE 31. Podzol in the sclerophyllous mountain forest zone at 5300 ft.

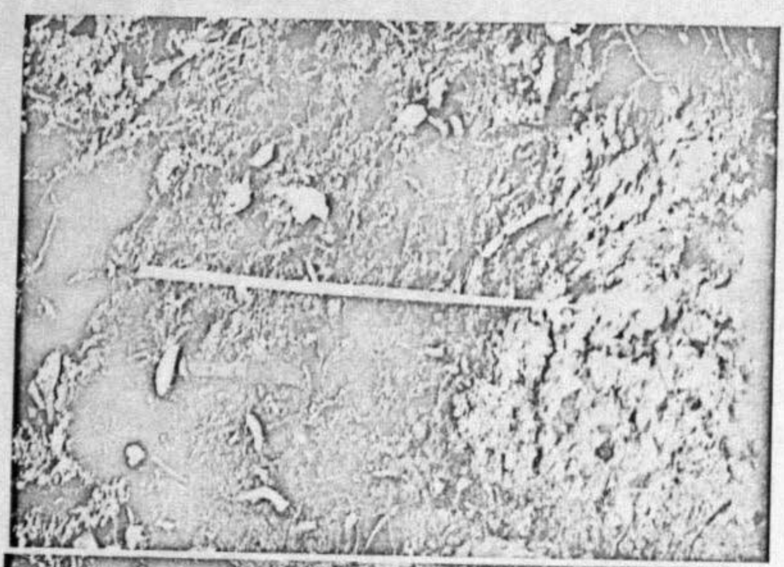

FIGURE 32. Peaty gley soil in the moss forest zone at about 8000 ft.

(*Facing p.* 72)

earthworm populations at pH 4·0 in the alpine humus soils of New South Wales and such occurrences could doubtless be matched from other montane areas.

On less steeply sloping sites (i.e. slopes of about 20 to 30°) the granodiorite is more deeply weathered to about 175 to 250 cm and here occur two dissimilar soil types. On some sites the soil is superficially similar to temperate brown earths in that it has thick brown coloured (7·5 YR 5/6) horizons below the dark grey-brown, mull-like A_1 surface horizons of higher organic matter content. At depth the brown horizons grade into paler coloured disintegrated granodiorite. In thin sections the soils have a spongy erde fabric similar to that of brown earths.

TABLE 9. CHEMICAL ANALYSES OF A DEEP MULL SOIL (PROFILE B 9) DEVELOPED ON GRANODIORITE AT 9600 FT.

depth (cm)	pH	organic carbon (%)	carbon–nitrogen ratio	% base saturation	exchangeable Ca/Mg ratio	$\frac{SiO_2}{R_2O_3}$ (< 2·0 μm)
0–12	3·7	29·0	26	12	0·20	n.d.
12–28	4·2	10·5	24	13	0·36	1·05
28–40	4·7	5·8	23	24	0·34	0·85
40–56	4·7	6·0	26	22	0·28	0·41
56–84	4·5	4·3	21	19	0·21	0·85
84–117	4·5	3·7	20	14	0·30	1·26
117–186	4·4	1·8	20	13	0·60	n.d.
204–229	4·3	0·7	14	2	0·13	n.d.

Analyses (table 9) show certain striking differences. First, the carbon–nitrogen ratios remain greater than 20 to depth and, secondly, the silica–sesquioxide ratio of the clay fraction, which in temperate brown earths is of the order of 2·0, is less than or close to 1·0. The clay fraction is high in alumina and whilst no mineral determinations are yet available it seems certain that the secondary minerals in the soil must contain a high proportion of gibbsite or other alumina minerals. Whilst the soil contains relatively unaltered silicates (both feldspars and hornblendes) to the surface it would appear that under these strong leaching conditions in which the rainfall is greater than a 100 in. and the regolith is coarse textured, gibbsite is being formed. If this is so it will be in agreement with Barshad & Rojas-Cruz (1950) who found gibbsite formed during the weathering of an acid tuff in Colombia at 8000 ft. and Becket & Hopkinson (1961) who report large amounts of gibbsite in a soil developed on a relatively acidic igneous rock at 4800 ft. in the moss forest of Sarawak. Further evidence of the very strongly leached character of these soils is provided by the low Ca/Mg ratio of the exchangeable ions.

In the same area on similar slopes and often in close juxtaposition to these brown soils are other soils characterized by the presence of a thin iron pan directly below the granular surface horizon and above a brown coloured weathering horizon (figure 35, plate 2). The pan has similar morphological features to the thin iron pans present in the peaty gley podzols and peat podzols so common in the moorlands of upland Britain (Crompton 1956). Sometimes there is a small amount of pale coloured material present in pockets in downward projections of the pan, but usually mull-like A_1 horizon material directly overlies the iron pan. Thin sections

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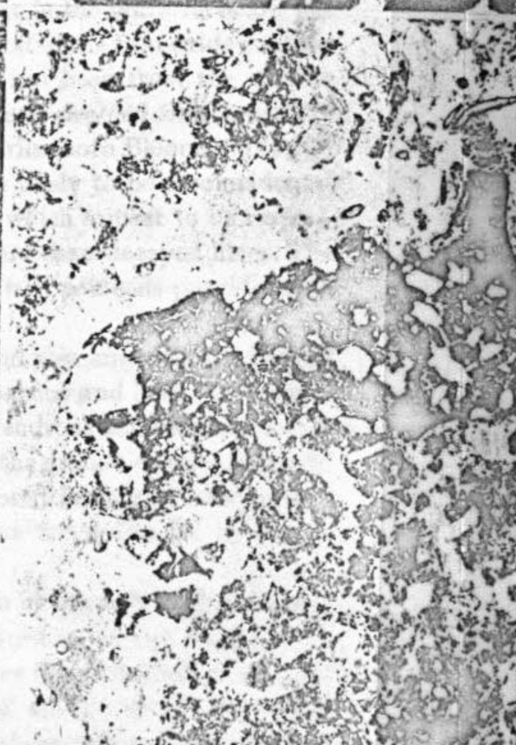

FIGURE 33. Shallow soil of a ranker type overlying granodiorite at 9800 ft.

FIGURE 34. Coarse sized granular structures from the ranker soil illustrated in figure 33.

FIGURE 35. Soil with thin iron pan developed on granodiorite at about 10 200 ft. In the centre of the profile there is a pocket of paler coloured A_2 horizon material present above the downward lobe of the pan.

FIGURE 36. Microphotograph of a section across the thin iron pan present in the profile illustrated in figure 35 (×3·3).

of the iron pan (figure 36, plate 2) show its sharp upper margin and more merging lower boundary, a feature which is also characteristic of the thin iron pans in temperate peaty gley podzols. Analyses (table 10) of the more readily extractable iron oxide of the whole soil show the leaching of iron from the surface horizons (< 0·5 % 'free' iron oxide) and its concentration in the pan (14 to 20 % 'free' iron oxide). The clay fractions again have a high alumina content and reveal in the molecular silica to sesquioxide ratios the differential movement of sesquioxides and their accumulation near the pan.

Table 10. Chemical analyses of a typical soil (profile B 19) with thin iron pan on granodiorite at 10000 ft.

depth (cm)	pH	organic carbon (%)	carbon–nitrogen ratio	'free' Fe_2O_3 (%)	$\frac{SiO_2}{R_2O_3}$ (< 2·0 μm)
0–3	4·0	18·2	22·2	n.d.	n.d.
3–28	4·2	11·6	18·8	0·54	1·82
28–41	4·0	10·1	23·5	0·33	0·94
41–54	4·1	3·8	25·8	0·90	0·45
54–55 (PAN)	—	—	—	14·20	—
55–86	4·1	1·9	21·9	2·44	0·72

These soils show no signs of mottling or poor drainage in the horizons below the iron pan. The morphology of the pan and the distribution of the iron oxide content of the clay and whole soil show that the movement has been from the surface downwards. Mobilization of iron and aluminium on freely drained sites is usually associated with a mor humus form, but as mentioned earlier both Bloomfield (1955) and Coulson *et al.* (1960) have pointed out that this is likely to be a coincidental rather than a causal relationship, for the polyphenols which appear to be responsible for podzolization are most abundant in fresh rather than decayed litter. The occurrence of iron mobilization in these mull-like thin iron pan soils provides field evidence in support of their views.

On the most exposed parts of the 10300 ft. ridge and also amongst the base of the pinnacles at about 11750 ft. earthworms are infrequent and here the skeletal soil developed under the dwarf thicket forest of rhododendrons and vacciniums has a fibrous litter layer. Elsewhere the mull-like soils on the granodiorite continue to high altitudes—indeed, a highly granular soil composed largely of earthworms castings was found developed in rock crevices only a few feet below the summit of Low's Peak.

In conclusion I must emphasize that our knowledge of the soils of Kinabalu is still at the descriptive stage and even this largely confined to the east ridge; we as yet know little about their development, their biology or their interaction with the ecology of the area. Despite the concentration of soil studies on the east ridge during the 1961 expedition our knowledge of the field characteristics and distribution of the soils of even this area is by no means complete. In particular I would have liked to have spent more time examining the soils of the moss forest and also the soils below 3000 ft. in the lower levels of the dipterocarp forest. It is hoped that during the 1964 expedition it will be possible not only to consolidate these earlier studies on the east ridge but also to extend the field studies to other areas, especially to the Pinosuk plateau, and to altitudinal sequences on the other rock types.

I am indebted to Wye College, University of London, for the leave of absence which enabled me to take part in the expedition. I would also like to acknowledge gratefully the continuous encouragement that I have received from Mr E. J. H. Corner, F.R.S., and the help I have had from Mr H. T. Jobson, analyst to the School of Agriculture, and also from Miss E. Anderson and Miss J. M. Robson in the chemical analyses of these soils.

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SOIL CONDITIONS IN SOME BORNEAN LOWLAND PLANT COMMUNITIES

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DURING A VISIT to Brunei and northern Sarawak in March-April 1959 I took the opportunity of examining soil profiles and collecting soil samples in each of the major primary lowland plant communities of the area. In addition to Mixed Dipterocarp forest and Heath (Kerangas) forest, these include the four principal types of Peat Swamp—Mixed Peat Swamp, the two types dominated by *Shorea albida,* viz. Alan and Meranti Bunga, and Padang Paya (*Combretocarpus-Dactylocladus* community). The soil samples were air-dried and subsequently analysed. I have to thank Mr. S. E. Allen of the Nature Conservancy's Chemical Service, Merlewood, Grange-over-Sands, Lancs for carrying out the analyses. This study of soils was undertaken in the hope of throwing some light on the ecological factors actually responsible for the very striking differences in physiognomy and floristic composition between these six plant communities.

The results of the analyses (without the descriptions of profiles etc.) are presented in Tables 1–3. During transit a number of the bags containing the samples were damaged and some samples, including some which might have been particularly interesting, were lost: there is also a suspicion that some of the samples may have been contaminated by some liquid during the sea voyage. Further, I cannot claim to be a soil expert and I am not sure that the soil characteristics measured or the methods used in the analyses were the best for the object in view. For these reasons, and because the number of samples is small, I think it is very doubtful if any firm conclusions can be drawn from my data, other than certain negative conclusions which I shall mention later. The data are presented here in the hope of stimulating some discussion on the factors, which are undoubtedly edaphic, differentiating the habitats of the communities I was studying.

I would like first to make some comments on the results of the analyses themselves, comparing first the two types of lowland climax forest and then the four types of peat swamp; I shall then express some opinions on the probable ecological factors concerned.

RESULTS OF THE ANALYSES

Mixed Dipterocarp forest and Heath forest. Because of their porous sandy texture and deficiency in clay fractions, Heath forest soils would be expected to be poor in nitrogen and bases compared to Mixed Dipterocarp soils and it is

TABLE 1.—SOILS OF MIXED DIPTEROCARP FOREST

	pH	L on I %	C Total %	N Total %	NH_3 Extractable mg./100 gm.	NO_3 Extractable mg./100 gm.	P Total %	P Extractable mg./100 gm.	K Extractable mg./100 gm.	Ca Extractable mg./100 gm.
11. Andulau, slope										
1 (Surface litter)	3.7	3.8	2.6	0.85	1.0	0.01	0.005	0.5	5.8	3.3
2 4 in.	4.5	1.6	Negl.	0.25	0.5	0.01	0.004	0.2	1.5	3.1
3 2 ft.	4.9	2.9	Negl.	0.35	0.7	<0.01	0.005	Negl.	2.8	1.4
12. Andulau, ridge top										
1 Ao	3.8	6.8	4.8	0.16	1.7	0.02	0.006	0.7	9.8	4.1
2 2—8 in.	4.8	3.4	Negl.	0.60	0.9	0.01	0.005	0.3	5.8	3.1
3 2 ft.	4.8	3.5	<1.0	0.27	0.3	Negl.	0.005	Negl.	4.5	<1.0
13. Andulau, ridge top										
1 ½—4 in.	4.0	6.0	3.4	0.20	1.3	0.09	0.014	0.1	10.3	4.3
2 6—12 in.	4.7	5.2	1.6	0.96	1.2	0.02	0.013	0.1	12.0	3.8
3 20—24 in.	4.5	6.0	1.0	0.09	2.0	0.01	0.013	Negl.	13.0	1.4

TABLE 2.—SOILS OF HEATH (KERANGAS) FOREST

	pH	L on I %	C Total %	N Total %	NH_3 Extractable mg./100 gm.	NO_3 Extractable mg./100 gm.	P Total %	P Extractable mg./100 gm.	K Extractable mg./100 gm.	Ca Extractable mg./100 gm.
1. Badas, F.R., plateau										
1 0—10 in.	3.3	47.3	Negl.	0.45	4.6	0.04	0.011	3.9	30.0	4.7
2 10—17 in.	5.3	0.3	<1.0	0.05	0.5	0.01	0.001	0.1	3.8	3.3
3 17—48 in.	5.9	0.1	Negl.	0.05	<0.1	Negl.	0.001	0.1	3.0	<1.0
2. Badas, F.R., slope										
1 4 in.	3.4	8.1	5.8	0.12	2.7	0.01	0.006	1.2	15.0	6.0
2 24 in.	5.6	0.5	Negl.	0.10	0.4	<0.01	0.001	0.1	3.8	3.4
3. Badas, F.R., plateau										
1 6 in.	3.4	19.5	7.6	0.22	2.9	0.01	0.009	3.4	16.8	3.1
2 15 in.	5.7	0.2	<1.0	0.06	0.1	0.01	0.009	3.4	1.8	3.6
3 24 in.	6.1	0.2	<1.0	0.21	0.2	Negl.	0.001	0.1	2.3	<1.0
6. Badas, F.R., plateau										
1 6 in.	3.3	80.3	49.0	1.19	8.5	0.09	0.033	10.6	40.0	4.5
2 15 in.	4.2	4.5	3.4	0.54	1.7	0.01	0.007	0.5	5.3	4.9
3 24 in.	5.7	0.3	<1.0	0.06	0.2	<0.01	0.001	0.1	2.3	<1.0
7. Badas ('giant podsol')										
1 6 in.	4.4	1.2	1.0	0.42	0.5	0.03	0.003	0.5	3.5	4.3
2 30 in.	5.6	0.1	Negl.	0.05	0.3	0.01	0.001	0.1	2.5	3.3
3 Mixed sample from	5.3	2.9	Negl.	0.28	0.4	Negl.	0.004	Negl.	3.3	Negl.
16. Marudi F.R.										
1 0— 5 in. (A0)	3.7	11.3	9.8	0.21	3.6	0.01	0.014	3.2	24.0	2.7
2 5—12 in. (A1)	5.8	0.2	<1.0	0.07	<0.1	Negl.	0.004	0.1	3.0	3.3
3 24—28 in. (B)	5.2	1.1	Negl.	0.17	0.6	Negl.	0.005	0.1	5.5	Negl.
4 34 in. (C)	4.7	1.7	Negl.	0.35	0.4	0.01	0.007	0.1	5.0	Negl.
22. Berakas (Secondary vegetation)										
1 12 in. (A1)	4.5	0.8	Negl.	0.14	0.4	0.01	0.001	0.1	1.3	3.0
2 4½ ft. (A2)	5.7	0.2	<1.0	0.03	0.2	—	0.002	0.1	2.0	<1.0
3 8 ft. (B)	4.9	2.9	1.4	0.26	0.9	0.02	0.009	0.2	7.5	<1.0
4 Below B	5.4	1.1	Negl.	0.16	0.4	Negl.	0.012	1.2	3.0	<1.0

Table 3.—Peat Swamp Soils

In each profile sample 1 was taken from above water level and sample 2 from below it (to a depth of 12 in.). Water was squeezed out from the samples by hand before they were dried.

	pH	L on I %	C Total %	N Total %	NH3 Extractable mg./100 gm.	NO3 Extractable mg./100 gm.	P Total %	P Extractable mg./100 gm.	K Extractable mg./100 gm.	Ca Extractable mg./100 gm.
8. Mixed Peat Swamp, S. Belait, Site 1										
1	3.4	95.7	47.7	2.24	28.7	0.37	0.093	19.0	65.0	14.6
2	3.6	95.1	>50	1.67	9.4	0.07	0.036	3.5	42.5	26.2
9. Mixed Peat Swamp, S. Belait, Site 2										
1	3.6	96.8	48.5	2.10	55.0	0.34	0.103	18.1	87.5	14.0
2	3.7	91.5	>50	1.66	15.5	0.06	0.046	3.9	35.0	9.1
10. Mixed Peat Swamp, S. Belait, Site 3										
1	3.7	92.6	47.3	1.97	33.7	0.20	0.075	12.2	65.0	15.9
2	3.6	94.7	49.6	2.03	16.9	0.07	0.051	4.4	52.5	11.5
19. Alan Swamp, Seria (margin)										
1	3.7	89.0	>50	1.90	34.5	0.15	0.076	16.0	100.0	14.1
2	3.6	93.6	>50	1.35	10.2	0.03	0.036	5.1	60.0	8.9
20. Alan Swamp, Seria, interior										
1	—	—	—	—	—	—	—	—	—	—
2	4.0	93.2	>50	1.58	11.0	0.08	0.045	7.6	55.0	10.0
21. Alan Swamp, Seria, further										
1	—	—	—	—	—	—	—	—	—	—
2	3.7	94.7	24.3	1.20	7.9	0.01	0.029	5.3	45.0	14.0
4. Meranti Bunga, Badas (disturbed?)										
1	4.0	94.7	49.3	1.90	26.3	0.14	0.087	33.3	110.0	154.5
2	3.7	93.1	50	1.47	16.9	0.40	0.069	9.5	47.5	25.8
5. do. (less disturbed)										
1	3.5	98.0	>50	1.41	21.7	0.36	0.056	17.0	50.0	13.0
2	3.8	96.1	>50	1.12	13.8	0.36	0.028	4.8	47.5	12.6
14. do. (undisturbed)										
1	3.4	94.6	>50	1.69	23.8	0.07	0.042	12.4	50.0	14.6
2	3.5	81.7	38.6	1.12	14.1	0.02	0.021	6.7	52.5	13.3
18. Padag paya, Marudi (margin)										
1	3.5	98.9	>50	1.36	9.0	0.16	0.024	4.9	77.5	8.8
2	3.8	93.1	47.4	1.48	11.0	0.05	0.020	4.5	60.0	5.0
17. do. (central area)										
1	—	90.3	—	1.65	—	—	—	10.7	65.0	9.1
2	3.7	98.0	46.4	1.44	20.4	—	0.043	16.5	97.5	12.9

of course well known that they are much less fertile when brought into cultivation. Hardon (1937) found that the *kerangas* soils of the Bangka and East Borneo padangs were very deficient in bases and plant nutrients generally. It is interesting therefore that the data in Tables 1 and 2 do not seem to show much difference in the *chemical* characteristic (as determined on dried samples) of soils from three sites in the Mixed Dipterocarp forest of the Andulau Forest Reserve (Table 1) and those from five *kerangas* profiles at Badas and two from other Heath forest sites (the last not primary).

There is some indication that total nitrogen is slightly lower in the Heath forest soils than in those of the Mixed Dipterocarp forest, but there is no evidence of a difference in ammonia or nitrate. It is doubtful however whether determinations of total nitrogen, ammonia and nitrate on dried samples such as these have much significance; measurements of nitrification and available nitrogen on fresh soil samples would be more likely to give useful results. The figures for total and extractable phosphorus and for calcium and potassium do not indicate any significant differences between the soils of the two communities. All these forest soils have a very low content of bases and plant nutrients generally.

Peat Swamp communities. The peat swamp samples were obtained from three profiles in Mixed Swamp forest on the S. Belait near Kuala Belait, from three profiles near together in the alan swamp near Seria, from meranti bunga peat swamp sites near the Badas railway and from two profiles in the padang paya of the large peat swamp near Marudi on the S. Baram; unfortunately two of the alan samples and the greater part of one of the padang paya samples were lost in transit.

In each peat swamp profile one sample was collected above the water level and one below it (to a depth of about a foot). The peat samples mostly had the consistency of porridge and had to be squeezed in the hand to get rid of surplus water. All the peat samples except those from the padang paya were extremely retentive of water and could only be made dry enough to pack by long drying in the sun. This long drying may well have caused considerable microbiological and other changes, so that the content of nitrogen may have been widely different when analysed from what it was in the fresh samples.

Bearing all this in mind, we may note in the analyses first of all that the peat samples are in general more acid than the Mixed Dipterocarp and Heath forest soils. A puzzling feature is the relatively high values for potassium and calcium compared with the forest soils. It has to be remembered that as each sample represents a very much larger volume of peat-water mixture, the mineral ions are in fact concentrated from a much more dilute solution. Even allowing for this, the values seem surprisingly high, as do those for phosphorus, ammonia and nitrate; one would expect peat swamps, especially the padang paya, to be highly deficient in all these nutrients. It is possible that there has been contamination or some other unsuspected source of error.

There seems to be remarkably little difference between the results for the different peat swamp communities, though it is hard to believe, for instance, that the padang paya is not more deficient in plant nutrients than the Mixed

Peat swamp, since the former is subject to continual intense leaching by rain and would appear to have no source of additional mineral supplies except the atmosphere, while the former presumably receives nutrients in solution both in drainage water and from river flooding. The nitrogen and mineral supplies in these swamp peats clearly require further examination; more samples and different methods should be used.

EDAPHIC FACTORS DIFFERENTIATING THE COMMUNITIES

Mixed Dipterocarp forest and Heath forest. It is very obvious that these two communities are determined by different soil conditions; both appear to be climax communities and both occur under the same climatic conditions. Heath forest, as has long been known, occurs only on bleached sandy soils with an A o layer showing mor characteristics. These soils, if not all true podsols, are podsolic in type and are strikingly different from the yellow latosols etc. on which the Mixed Dipterocarp forest is found. Where there is a sharp boundary between the two soil types there is, as I have pointed out in my paper on the vegetation of G. Dulit (1936), an equally sharp transition from one forest type to the other. The contrast between the two types of vegetation is as striking and clear as that between the vegetation of calcareous and base-deficient soils in many parts of Europe, though of course the edaphic factors concerned are quite different.

Heath forest differs from Mixed Dipterocarp forest in a large number of characteristics, only some of which need be mentioned here. Though I have no precise data for the height and basal area of the trees or the timber volume, there appear to be fewer large trees and probably fewer very tall trees in Heath forest; one would expect to find that the total biomass and productivity of the Heath forest are much less than those of the Mixed Dipterocarp forest. In this connection it has struck me that the relative absence of leeches in Heath forest may be partly due to a smaller population of animal hosts; perhaps someone present can say whether there is any evidence for this.

The Heath forest has a strikingly different floristic composition from the Mixed Dipterocarp forest. Though some species are common to both, many (I cannot say how many) are confined or nearly so to one or the other. Many genera, e.g. *Hopea, Eugenia,* are represented in the two communities by different 'Vicarious' species.

Heath forest plants, especially the trees, in general tend to have smaller and thicker leaves than their relatives in the Mixed forest; striking examples are the Heath forest species *Hopea vaccinifolia* and *Eugenia* sp.cf. *bancana.* Putting this in other words we can say that Heath forest vegetation has marked xeromorphic characteristics. It was in fact probably its xeromorphic appearance which led Hubert Winkler in his paper on the vegetation of South-east Borneo (1914) to give this type of vegetation the name *Heidewald* (Heath forest); the xeromorphic characteristics of the Heath forest vegetation reminded him of the xeromorphy of the heath vegetation of N. Germany.

Now Schimper's theory that the xeromorphy of heath and acid bog plants is the expression of some sort of 'physiological drought' has been very thoroughly discredited by the work of Montfort and others and has long been abandoned.

The modern view tends to connect the xeromorphy of plants in acid peat bogs and similar habitats with nutrient deficiency, especially nitrogen deficiency, rather than with any kind of water deficiency.

If this view is accepted one might expect the Heath forest soils to show nutrient deficiencies and to have less available nitrogen than the Mixed Dipterocarp soils. If my data are taken at their face value however this does not seem to be so and one is tempted to suggest that it is some *physical* edaphic factor such as aeration or water-supplying power might be responsible for the very characteristic vegetation of these soils. Before accepting such a conclusion however much further study of kerangas soils is necessary. It is evident from the appearance of Heath forest profiles and from what is known of podsolic soils in temperate climates that the microbiology of these soils is probably very different from that of Mixed Dipterocarp soils. This would be a fruitful subject for investigation and if there are important microbiological differences they might well have a considerable influence on the *availability* of nitrogen and perhaps other nutrients to the vegetation.

Peat Swamp communities. On well developed peat swamps in Brunei and Sarawak the various communities occur typically in a series of concentric zones, of which the Mixed Peat swamp (corresponding more or less to the rand of temperate raised bogs) is the outermost, occupying situations where flooding by river water can occur. The innermost, seen in an extreme form in the semi-open padang paya (*Combretocarpus-Dactyloclados* community) of the Marudi peat swamp, occupies the raised central area and receives water supplies only from the rain. Whatever the true dynamic successional relations of the various peat swamp communities (and further investigations on this are needed) it is evident that there must be considerable edaphic differences between, e.g. the two extreme communities, the Mixed Peat swamp and the Padang Paya. The other peat communities, such as the *Shorea albida* communities, might be expected to be intermediate in edaphic conditions.

As mentioned above, my data do not seem to bear this out, but for the reasons already given I am not inclined to place much reliance on this. The Padang Paya is clearly a very mineral-deficient community; its vegetation is low, small in total bulk and shows marked xeromorphic characteristics. The plants on the Marudi Padang Paya appeared to me to show many of the well known symptoms of mineral deficiency. Not only is the total biomass (for a lowland tropical plant community) small, but the apparent scarcity of insect, bird and other animal life suggests that it is an ecosystem of very low productivity. In contrast to this the Mixed Peat Swamp is much more luxuriant; the biomass must be not very different from that of a normal Tropical Rain forest. Productivity must be much higher and the vegetation does not show any marked xeromorphic features. All this must surely depend on a better supply of mineral nutrients, brought in partly by the centrifugal drainage of the peat swamps, and partly by silt and floodwater from periodic river floods.

A series of small sample plots which I laid out in 1959 in order to draw profile diagrams showed a remarkably regular decrease in the number of tree species from the peripheral to the central peat swamp communities, viz, Mixed Peat Swamp 20, Alan 13, Meranti Bunga 11, Padang Paya 4, and a gradation in various other features, even in such things as the abundance of *Nepenthes* spp. which rises steadily from the Mixed Swamp to a maximum in the Padang Paya. One is forced to conclude from these facts that the peat swamp communities are a graded series depending on increasingly less favourable edaphic conditions. In spite of my apparently contradictory data, I would suggest that the availability of nitrogen and/or some other nutrient such as phosphorus may be the factor mainly responsible.

For several reasons it is difficult to compare these analyses of Bornean swamp peats with published figures for peats from raised bogs etc. in temperate regions. It seems however that the Bornean peats are even more deficient in elements such as phosphorus, potassium and calcium.

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DISCUSSION

WYCHERLEY:

Recently we have rooted green cuttings of mature-type *Hevea* by keeping them under continuous mist during the day and there is a very definite leaching of the leaves, perhaps by washing away of nutrients secreted through the stomata, and this can be corrected by foliar application of soluble fertilizers in the evening when turning off the mist for the night. Could the xeromorphic features be adaptations to reduce the loss of nutrients in short supply? Has mineral analysis of the foliage of plants common to more than one community been attempted to see what is the nutrient status of the plants themselves? Foliar analysis has been a very valuable technique in crop plants.

RICHARDS:

A recent paper has shown that this would have been useful, as the modern views tend to connect the xeromorphy of plants with nutrient deficiency.

FOSBERG:

Has any relationship been observed between the acidity of the soil and the ability of plants to take up the nitrogen which is available?

BAILEY:

The analysis of about 7,000 soil samples, including many from residual soils, has shown that there are only small differences in the levels of acidity and "available" nutrients despite vegetation differences.

Exchangeable methods of nutrient extraction were used, and it is thought that the small analytical differences are not significant because of the small number of samples collected from each site and the inherently large error when measuring small quantities.

However, using "old-fashioned" concentrated acid extraction methods, larger nutrient differences are being observed which appear, in some cases, to correlate better with vegetational differences.

WALKER:

Perhaps one of the most important points which Professor Richards' paper underlines is the danger of seeking to obtain significant results from the analyses of soils remote from their place of origin and after drying out over a long period. Peat soils of different initial pH may show a drift of pH in the acid direction on partial drying out and rewetting. During a period of 24 hours a drift of up to 2 pH units may occur, and the magnitude of this seems not to be directly related to the initial value.

RICHARDS:

I agree with you, and would not claim that the pH values given are accurate. However dry the Brunei part of the forest, I hope to be able to take a fresh set of readings *in situ*.

FOSBERG:

Is it not possible that much of our trouble with pH may be due to attempts to be precise? One would expect a considerable variation in any feature of a complex phenomenon such as soil. It seems to me that the accuracy of one of the simple colourimetric field pH kits is perfectly satisfactory for this type of work, and determination can be made within a few seconds after securing the sample, thus eliminating the drift or change due to drying and change in microbiota.

RICHARDS (on WALKER):

I am trying to make a comparison with the results obtained by Malone and Sjover. The nitrogen levels appear to be much the same as those obtained from the Brunei samples.

GILLETT:

I would like to emphasize that mineral deficiencies in a bog might well be due to the unavailability of a given nutrient under the acid conditions of the bog, so that the mere analysis of the bog solution for nutrient content might be misleading.

RICHARDS:

Availability is probably the key to the problem.

GILLETT:

It would seem most unlikely that a nutrient deficiency could be attributed to foliar leaching. Nutrients are taken up by active absorption and rapidly enter into the metabolism of the plant, passing from the xylem to the phloem very rapidly.

WYCHERLEY (on GILLETT):

There is direct evidence by analysis of rain drip from leaves that potassium is lost in this way—presumably through leaching.

FOSBERG:

I might point out that in the Abijian Symposium it was mentioned that in an African rain forest ecosystem there was a very considerable loss of potassium due to leaching by rain.

WEBB:

Ferri in Brazil has shown that the so-called "xeromorphic" vegetation of the Campos Cerrados is not limited by water, but nutrients. Our widespread "dry evergreen" or sclerophyll vegetation in Australia occurs over a wide range of moisture availability and can similarly be correlated with soils of low fertility.

DILMY:

You speak about Combretocarpus-Dactylocarpus community. Do you not mean Combretocarpus-Dactyloclados?

RICHARDS:

Yes, I mean Dactyloclados. It is a typing error.

Symp. on. Ecological Research in Humid Tropic Vegetation 1963.

A STUDY OF THE CORRELATION BETWEEN SOME SOIL FACTORS AND THE DISTRIBUTION OF FOUR TREE SPECIES AND THEIR REGENERATION IN THE SUNGEI DALAM FOREST RESERVE, SARAWAK

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SUMMARY

1. From data collected in the sampling of 164 soil borings in February and May 1958 in the Dalam Block of the Jambir Forest Reserve, the various podsolic kerangas and acidic peat soils were classified and their distributions mapped. The distributions of four prominent tree species growing in the block, *Casuarina sumatrana* (Ru Ronang), *Shorea albida* (Alan), *Dacrydium* sp (Sempilor) and *Agathis alba* (Bindang) were mapped separately in two-inch diameter size classes from forest enumerations made in 1952 and 1956. Comparison of the soils and species distribution maps confirmed field observations.

2. A study of the relationship betweeen the depth at which the organic pan appears in the podsolic kerangas and the establishment of regeneration of Sempilor showed that apparently none exists. The thickness of the accumulation of mor humus over the mineral soil is considered as the limiting factor.

3. The conclusions which can be drawn from the above studies indicate that regeneration of Ru Ronang and Sempilor, which can be found, is not likely to become established. Alan, due to its infrequent seed production and normal peat soil habitat, will be also unlikely to reproduce itself here. The changes which will follow in the composition of the forest will reflect or be reflected in changes in soil conditions. The cradle-knoll micro-relief of the area should change little and the soils will either become peatier with thicker mor humus accumulation or drier with shallower accumulations.

4. In areas where these three species are not found, that is, on the rising land to the south of the reserve where the kerangas soils have a clay content, changes are not expected. The forest cover is a more stable lowland dipterocarp forest type capable of reproducing itself.

AIMS

1. The aim of the study, under the original terms of reference from the then Conservator of Forests, Mr. F. G. Browne, was to discover if the depth of the organic pan in acidic Kerangas soil had any effect on the regeneration of the coniferous species Sempilor (*Dacrydium*). This was later extended to to see if any correlation existed between the soil types found in the Dalam block of the Lambir Forest Reserve and four tree species. These species, *Casuarina sumatrana* (Ru Ronang), *Agathis albida* (Alan) were chosen as they are all Kerangas soil indicators and are found in sufficient numbers to make correlations possible.

2. The Lambir Forest Reserve is situated near the coast and a few miles to the south of Miri in the Fourth Division, Sarawak (see map 1). Its elevation ranges from about 100′ above sea level to 1,525′, the top of Bukit Lambir. The terrain is very variable from steep-sided bare rock ridges on Bukit Lambir to lowly undulating Kerangas and localised flat peat swamps. The block studied lies on the two latter types in an area formerly called the Sungei Dalam Forest Reserve.

3. The rock formations here are of Tertiary sandstone covered, near the coast, by raised beach terraces. The topography of the area is described by Dames* as being of "cradle-knoll micro-relief". This is borne out by levels taken which show an overall fall to the west but with slight undulations. To the south the rise is more pronounced but again slight undulations appeared. This southern rise continues into the lower slopes of the Bukit Lambir. The slight undulations are exaggerated in the densely stocked Ru Ronang, Alan and Sempilor forest where, on the high stilt and buttress roots of these species, suspended organic matter, matted leaves and slowly decomposing phyllodes, fine roots and fallen broken branches have formed a false ground level which rises and falls steeply over short distances. It can be difficult and dangerous to walk on.

4. The main river of the block is the Sg. Dalam which runs along its eastern boundary. Its source is in the foothills of Bukit Lambir and it has always some flow of clear water, even in dry spells. Smaller streams which tend to dry out in dry weather are found on the western boundary of the area and, draining the terrace to the sea, contain a brown-coloured water. The difference in the drainage water colours is explained by the land configuration which causes a north-westerly lateral movement of the brown-coloured peat and Kerangas drainage water over the impervious sub-peat clays and the hard organic pan. Sungei Dalam, by its down-cutting of the terrace, is now lower than the pan or impervious clays and therefore contains the clear water of hill soils drainage.

5. In general, Sarawak is influenced by the N.E. and S.W. monsoons with the former occurring from October to May and producing the wet season.

Rainfall in inches

Year	MIRI			SIBU			LONG LAMA		
	Feb.	May	Annual	Feb.	May	Annual	Feb.	May	Annual
1961	7.1	5.2		12.8	7.3		12.60	14.06	
1960	12.3	7.3	105.9	7.0	5.1	124.6	22.95	28.03	—
1959	2.0	8.2	113.7	7.4	13.5	133.5	19.55	21.72	237.41
1958	1.0	7.0	115.1	6.8	11.0	128.9	—	18.86	—
1957	2.9	12.2	111.0	6.8	10.9	113.6	12.13	27.49	—

* T.W.G. DAMES. F.A.O. Soils Expert. The quotation is from a note on the Sungei Dalam block written in 1956.

However, rainfall at Miri on the coast is usually less than at inland stations. The table shows this difference, and the irregularity of rainfall. Sibu, in the Third Division, is some 40 miles inland, but is not in hilly country whereas Long Lama, 70 miles inland, is.

6. The table shows that February weather in Miri is generally dry. Along the northern sea coast of Sarawak, and into Brunei, droughts have been experienced in the wet monsoon, to such an extent that a most exceptional fire occurred in the Anduki Forest Reserve in Brunei in February 1957.

Description of Soils

7. In all, 164 soil samplings were made and from them the soils found were classified as follows:— Peat, Kerangas (wet and dry) and loam.

8. This last soil was of least importance as none of the tree species being studied grows on it. It is an alluvial soil found on the river level of Sungei Dalam, its extent being limited to a very narrow, irregular strip before giving way to peat or Kerangas. A merchantable tree, *Dryobalanops aromatica* (Kapor), which is not found elsewhere in the forest, grows on this soil. A typical description of this soil is as follows:—

Line 4A Boring 3

0– 3″	Mor layer with surface litter, fine roots, sharp to
3–13″	Yellow brown massive clay with much rooting, plastic, slightly sticky, sharp to
13″ plus	Grey clay, plastic, sticky, with yellow mottlings. This layer continued to the depth of the augur, 54″.

9. A loam soil with podsolisation was found away from Sungei Dalam along the smaller tributary streams draining the terrace to the west and to the sea. A description follows:—

Podsolised Loam Boring 9H

0– 2″	Dry mor with rooting and admixed fine sand, sharp to
2– 8″	Fawn clay fine sand with much rooting, merging to
8–15″	Dark fawn clay medium sand with slight rooting, sharp to
15–27½″	White clay fine sand with slight brownish staining, merging to
27½–45″	White clay, sticky, plastic, no rooting
45″ plus	White clay with coarse sand and small quartz particles.

10. The peat soil type was not common, as classified for this study, being confined to soils with a deepish organic accumulation over a clay sub-soil. The descriptions therefore were all similar with variations only in the depth of the top horizon of 12″ to 48″ and more of decomposing, wet or dry organic matter. The clays beneath were generally wet but some were sampled which, impervious to the water suspended in the peat, were dry.

11. The peat soils were found adjacent to wet Kerangas types and being infrequent cannot have a great influence on the forest growth. An example of the type follows:—

Boring 1E

0–26″	Dark brown dry mor with surface litter and live rooting throughout
26–47″	Wet mor with live rooting throughout, sharp to

47″ plus Brown clay, dryish, very plastic, very sticky, no rooting. Beyond 54″ the soil becomes paler in colour.

12. The Kerangas soil type was found in the remainder of the area sampled. This type is similar in appearance to a temperate climate podsol with clearly banded mor humus, leached and hard pan layers. In Kerangas the leached layer is a nearly white sand and the pan a dark brown organic layer which, though generally hard, can sometimes be soft. The leached layer can be a few inches or several feet deep and the latter type has been referred to as a giant podsol. Variations in the mor layer depth also occur. Contrary to the temperate climate podsol this soil contains no iron, as can be shown easily by ignition. The pan and top mineral layers of the profile are extremely acidic and recordings of pH 3–4 are common. The leached white layer is generally less acidic in the pH 6–7 range.

13. Many profile variations were found in the Dalam block and, due to the cradle-knoll micro-relief, soils with a deep wet mor layer were found which, had they extended over large areas, might well have been called peat soils. These were termed wet Kerangas as, situated in depression, they collected water. In February, the drier month of sampling, soil water generally appeared at a depth of about 20″ but in May, during wetter conditions, surface water was frequent. Dry profiles were sampled with mor layers ranging from ½″ to 34″ in depth. Although Kerangas tends to be mainly a sandy soil, pockets of a fine sand clay type were found with both wet and dry conditions. The dry clay Kerangas in both February and May was extremely difficult to sample due to the hardness of the soil and thus the pan layer was not always reached. The horizon colours were not so extreme as in the sand Kerangas and pale fawns and browns replaced the leached white and dark browns. The wet clay Kerangas, with seepage water at 6″ or less from the soil surface, was easier to sample and did not prevent the pan layer, if not deeper than the augur length, from being found. Clay was generally found throughout the upper horizons but not always in the pan layer.

14. There are more dry Kerangas soil types in the area than wet. The clay Kerangas was not classified separately but differentiated only into the wet or dry types, this decision being determined by the knowledge of the tree species being studied. Descriptions of profiles examined follow, exemplifying the various Kerangas soil types discussed above:—

Giant Podsol Type Boring 2A/3

0– 8″ Mor layer with surface litter and rooting, sharp to

8–16″ Brownish fawn medium sand with white quartz particles, admixed decomposing organic matter, slight rooting, sharp to

16″ plus A white medium coarse sand with no roots. At 28″ seepage occurred. Further auguring to 48″ has still not reached the pan layer.

Dry Kerangas (sand) Boring 5D

0–11″ Dry mor with surface litter and much

11–16½″ Wet mor with rooting and at 16½″ an admixture of fine sand, sharp to

16½–18″ Dark brown grey medium sand with much organic matter and fine rooting, sharp to

18–45″ Fawn white medium coarse sand with faint pale mottlings, sharp to

45″ plus Black brown medium sand pan soft at top hardening beneath.

Seepage into the boring occurred at 36″.

Wet Kerangas (*sand*) *Boring 8B* (*1*)

0–10″ Mor with matter roots, sharp to

10–16″ Yellow brown sandy loam with much rooting and organic matter, sharp to

16–26″ Grey white medium sand, no rooting or organic matter, sharp to

26″ plus A dark brown medium sand soft on top but hardening with depth.

Water table at 8″.

Dry Kerangas (*clay*) *Boring 16A* (*3*)

0– 4″ Mor with surface litter, sharp to

4– 7½″ Fawn grey fine sand clay with fine rooting and organic staining, sharp to

7½–16″ Hard compacted grey white fine sandy clay with slight organic staining, sharp to

16″ plus A dark brown clay pan, plastic and slightly sticky.

No seepage in this profile.

Wet Kerangas (*clay*) *Boring 12B* (*6*)

0– 3″ Mor with surface litter and much rooting, sharp to

3–36″ Fawn brown clay fine sand with organic matter and live rooting, sharp to

36″ plus Dark brown medium sand hard pan.

Water table at 2″ from profile surface.

Description of Forest

15. The forest throughout is a natural high forest which, other than through natural mortality, windblows and replacement, has not been disturbed except along the banks of Sg. Dalam where a few Kapor trees were illegally felled. As there is a considerable overlap of species on the several soil types it has been divided into three main broad types, Riparian, Kerangas/peat and a Ru/Alan/Sempilor forest. The latter type has been subdivided so that the small but distinctive areas of Bindang and Padang forest are recognised.

16. The riparian forest is of very small extent being limited to the levees of Sungei Dalam. It contains few trees, other than the conspicuous Kapor species not found elsewhere in the area, although there are small trees and much regeneration in the under storeys. There is little litter on the forest floor and paths show the mineral fraction of the soil. The forest floor is flat or very gently sloping into Sungei Dalam.

17. The Kerangas/peat forest is concentrated on the western edge of the block, starting where Ru Ronang does not grow. The forest is tall, up to 100′, with a dense top canopy. There is a great variety of species in this forest and certainly a greater frequency of the dipterocarp species. On the drier soils *Dryobalanops rappa* (Kapor Paya), *Dipterocarpus lowii* (Keruing Sol) and *Shorea* spp. (Meranti) are found with the less valuable and smaller tree species such

as members of the *Sapotaceae* (Nyatoh), *Calophyllum* spp. (Bintangor), *Tristania* spp. (Selunsor). In the wetter areas, in addition to the above, *Shorea pachyphylla* (Urat Mata) is found. Alan is found throughout this forest type except in the most southern area of the block.

18. The forest is well shaded by the dense top canopy and small trees and regeneration of all species fill the spacing from the forest floor to the canopy. There are many species which do not reach timber tree size. The forest floor is flat and progress is reasonably easy except where soft peat conditions are met.

19. The main Ru/Alan/Sempilor association has a very distinctive appearance at ground and canopy levels. The Ru and Sempilor species are both light branching and finely leaved trees. As the former is the most frequently found species in the block, the forest has a very open appearance which is not affected by the few heavy crowned Alan trees also present. The forest floor, as already mentioned, is very uneven by virtue of the stilt rooting of these three species and the deep accumulations of organic matter.

20. Although many other species are found growing within this forest type there is not the same density of growth as found in the Kerangas/peat type. Seedling Ru, Sempilor and Alan are hard to find although regeneration of the two former species is more frequent. Sempilor is found less frequently than Ru. Other species such as Bintangor, Nyatoh and *Combretocarpus rotundatus* (Keruntum) grow to reasonable size but the majority of the growth is of small-sized material and includes such species as Selunsor, *Parastemon urophyllum* (Ngilas), *Ploiarium alternifolium* (Somah), *Podocarpus neriifolius* (Kayu China).

21. The sub-type Bindang forest is similar in appearance to the main Ru/Alan/Sempilor type as these three species are all found within it. It is, however, on raised ground where the trees are less stilt-rooted and the forest floor is flatter. Bindang can be found at most stages of growth from seedling to mature tree and, concentrated in a small area, the forest is generally more shaded. Growth of other species due to better drainage and soil conditions is denser than in the main Ru/Alan/Sempilor type.

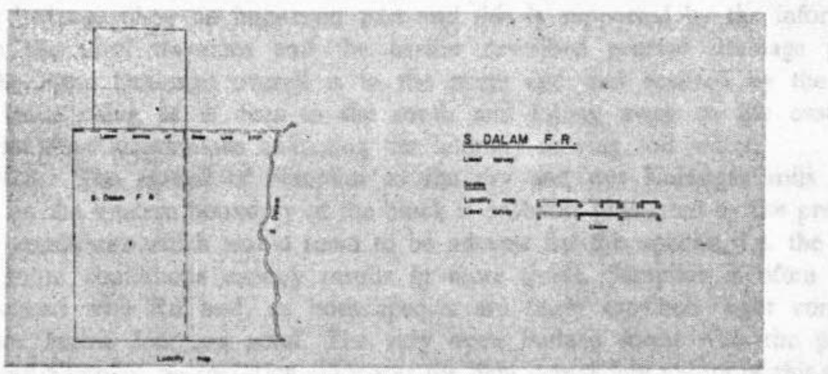
22. The Padang forest, as a sub-type of the main Ru/Alan/Sempilor forest, can be called a dwarf type as it contains all the usual species. The top height of growth in it does not exceed 50 feet and the average is nearer 30 feet. The forest can be densely stocked or nearly open and, in the latter, striking enough in itself, extremely good growth of young Sempilor can be seen. In the very open spaces ground litter is nearly absent. The bark of all the trees, particularly in the very open areas, seems to be toned to the same hue of dryness. This forest is found on the middle of the eastern half of the block.

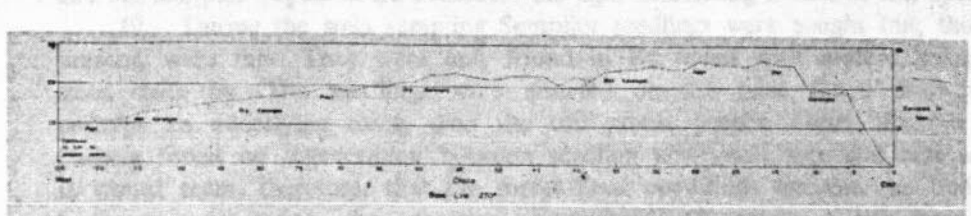
23. In all the forest types described above there are, in addition to the tree species, rattans, mosses, palms, small climbers and nepenthes in the floristic composition. Nepenthes are common throughout and orchids too, these latter being more noticeable in the open Ru/Alan/Sempilor forest where they grow at lower levels due to the better light conditions than those afforded by the riparian or Kerangas/peat forests.

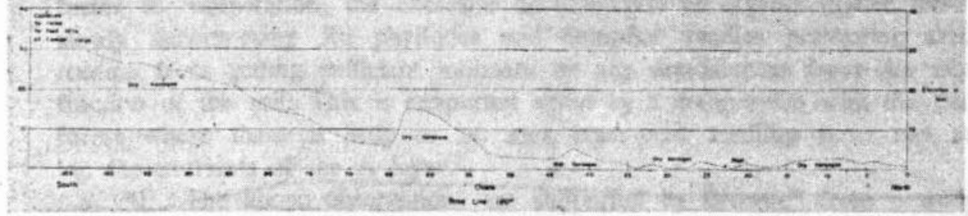
Field Work

24. This was done in February and May 1958 when soil descriptions were recorded from borings made by either a 9″ diameter post-hole borer or a 2″ diameter augur. The latter was used only in peat soils to test for peat depth at which the pan occurred, or to test the sub-peat mineral soil type. The borings in the northern 240-acres Section of the block were made at five chains intervals along nine traces, 10 chains apart. To sample the 15 chains gap between these sections six borings were made along an E—W trace formerly a reserve boundary. The traces used were otherwise those made during tree enumeration surveys in 1952 and 1956. The coincidence of soil sampling on these old enumeration traces was deliberate so that a close correlation of soils to species could be achieved. In the tree enumeration surveys the books were closed at five chain intervals and, from them, the maps of species distribution by size classes were made.

25. Soil profiles were recorded as far as possible in the manner described in the United States Department of Agriculture Handbook No. 18 of 1951 Section 6, although soil colours and pH values were not included. The values will be close to those recorded in a paper* on the coastal soils of Bintulu,







* "Some Sarawak Soils II Soils of the Bintulu Coastal Area" by Dr. P.H.T. Beckett & T.W.W. Wood, Journal of Soil Science, Vol. XII No. 2, 1961.

which described several Kerangas profiles including soil colour and acidity data.

26. Two traverses of levels with readings taken at one chain intervals were made in a "T" shape the leg running N—S. These were made to confirm visual estimations of land configuration and drainage patterns.

CORRELATIONS

Sempilor Dacrydium

27. From a quick comparison of the size class distribution map with the soils distribution map, this species seems to grow on all the soil types except the alluvial or podsolised loam soils. However, the distribution of the size classes is not even and closer inspection of these maps shows that similar soils in different parts of the reserve may, or may not, be populated. The most obvious distribution difference shows up between the 41″ maximum of girth found in the northern block compared with the main block, particularly to the east of the base line, where a girth range of 18″ to 120″ is found. The wet and dry Kerangas profiles in both these areas have the same wide variations in mor layer depth, moisture conditions and the depth at which the organic pan appears. There is a definite thinning out of the size classes in the wetter soils, particularly in the wet Kerangas clay type. It would seem, therefore, that drainage plays an important part and this is supported by the information from the level traverses and the earlier described general drainage pattern of the area. Drainage overall is to the north and east assisted by the lie of the land, rising as it does to the south and falling away to the east, with the localised depressions collecting the laterally moving soil water.

28. The spread of Sempilor to the dry and wet Kerangas soils or the peat on the western boundary of the block is probably prevented by the prevailing light conditions which would seem to be adverse for this species, i.e. the denser and more continuous canopy results in more shade. Sempilor is often closely associated with Ru and, as both species are finely crowned, light conditions on the forest floor are good. The very open Padang forest with the plentiful and tall Sempilor regeneration evidences the light demanding nature of this species.

29. During the soils sampling Sempilor seedlings were sought but, though present, were rare. They were only found in Ru forest with mature Sempilor trees close by. The seedlings were situated on the false forest floor with perhaps an underlying cavity over the soil profile proper. Other than in the Padang forest no regeneration between seedling and small tree size was seen. It would seem, therefore, that the forest floor conditions become the limiting factor to regeneration, the excessive accumulation of organic matter from the slowly decomposing Ru phyllodes and Sempilor needles preventing seedling rooting from getting sufficient moisture or any nourishment from the mineral fraction of the soil. This is supported again by a comparison with the Padang forest where there is little or no mor layer and seedling roots can easily tap the nutrients of the A layer.

30. The above observations are supported by Browne* from a study of

* "Kerangas Lands of Sarawak", by F.G. Browne, Malayan Forester Vol. XV, 1952.

Sempilor growing in very rich stands in peatswamp forest in the Lawas area. He says that the species does not reproduce. In the Dalam area also the accumulation of organic matter, wet or dry, and poor drainage is preventing reproduction. As drainage seems to be a strong factor in the growth of Sempilor it would seem that the deeper the pan layer the more beneficial it may be to tree growth.

Bindang (*Agathis alba*)

31. This species is found concentrated in the north-east corner of the block on the dry sand Kerangas soil type only, but a few scattered trees were enumerated on a similar soil in the central and southern parts. The soil typically is as described under the heading of "Giant Podsol". The site of main Bindang growth is on a low ridge close to Sungei Dalam on its left bank. Here drainage is good at all times and, due to free leaching, the organic mor layer does not develop great thickness although the persistent Ru phyllodes, Sempilor needles and the thick Bindang leaves do not decompose quickly. Although the Bindang within the reserve area is found only very localised, very much larger areas of good Bindang forest were exploited to the north and east of the Sungei Dalam block. Ru, Sempilor and other merchantable species such as Kapor, Meranti were also found. From previous examination of other Bindang forest soils it can be said that a freely drained sand Kerangas is necessary for this species. It regenerates fairly well but seemingly only in patches and in fairly open areas near to mother trees.

Ru Ronang (*Casuarina sumatrana*)

32. This species can be considered as a prime indicator for Kerangas soils but, as it can also grow on peat soils, its expected widespread occurrence here shows up clearly in a comparison of the size class and soils distribution maps. The density of the growing stock is not indicated on this map but about 50 trees per acre is a reasonable estimate. Though the stocking is dense the largest size recorded in the enumeration was 26" diameter at breast height. Throughout the Ru forest seedlings were frequent, but the chances of their becoming established on the sites with deep dry mor layers are as remote as those for Sempilor seedlings.

33. Apart from its expected avoidance of the riparian and podsolised loams, Ru was not found on wet Kerangas with clay. This is hard to explain but as Ru is considerably less frequent on the western edge of the area where soils are wet and dry, sandy or with clay, it may be a matter of drainage combined with competition from the heavy-crowned peat and Kerangas dipterocarps.

Alan (*Shorea albida*)

34. This species was found more widely spread than the three above species although less densely stocked only than Ru Ronang. It was, however, consistently the largest species and trees of over 120" in girth were common. It seems capable of growing on all peat and most Kerangas conditions, although, from the soils and size class/species distribution maps, does not extend into

dry Kerangas with clay. Elsewhere in Sarawak Alan grows on both peat and Kerangas soils, as evidenced by other enumerations, and in the Dalam block it has conformed to this pattern. Its non-appearance on the dry Kerangas clay may be due to the local dryness and hardness of these soils and the competition from other more prolific dipterocarp species. Alan regeneration was seen but rarely in the Dalam block and this is typical of the species.

35. As expected Alan did not appear on riparian loam at Sungei Dalam or on the other podsolised loams on the western side of the block.

Conclusions

36. This study did not provide any unexpected results but it did confirm casual field observations in the Dalam and other Kerangas forests. The soils are, for the greater part, of the podsolic acidic sands with variations in mor humus accumulation, texture and organic pan depth. Uniformity in the soils could not be expected as the composition of the forest cover showed wide differences over this relatively small area. The species Ru Ronang, Sempilor and Alan indicated that they could grow in a variety of soil conditions while Bindang showed a definite preference for sand soils with good drainage, shallow mor accumulation and a deep pan.

37. It would seem from the study that the regeneration of Sempilor is not likely to become well enough established to ensure its continued reproduction. This has been shown to be due to the thickness of the dry humus accumulation and to the depth at which the organic pan appears. Sempilor is a light demanding species and, although the light conditions at the forest floor are good, regeneration shows up only rarely and generally close to seedbearing trees. It does not appear as more than a seedling, other than in the area of Padang Forest where the mor humus accumulation is thin over a shallow soil. Mature trees are not found in the Padang but the growth of the small Sempilor trees is strikingly good, despite the apparently poor soil conditions.

38. The growth of Sempilor in the northern part of the block seems to have reached a limit of 41″ girth. On similar soils elsewhere there are trees of up to 78″ girth and the growth potential therefore would not seem to be affected by the depth at which the organic pan appears. The block of 41″ girth trees is clearly separated from the large trees suggesting a later occurrence, perhaps from a single seedling of the larger trees.

39. The regeneration of Ru Ronang is similarly handicapped to the Sempilor. It is a light demanding species but, although seedling regeneration is more profuse than Sempilor, it is no more likely to become established due to the dry mor humus accumulation. Alan, due to the infrequency of its seedling and its more normal peatswamp habitat, may be also not capable of reproduction. As the trees of this last species are considerably larger than both the Ru Ronang and Sempilor they are probably much older and are perhaps the relics of a previous pure stand. If this is true there would seem to be a change from wet to drier conditions taking place in the soil. This change will probably be evidenced less in the soil where only the thickness

and moisture content of the mor humus accumulation will alter. In the forest greater changes will take place and an invasion by the Dipterocarp species from the southern parts of the block is possible. As Bindang requires a specialised soil it is not likely to spread and in fact may be overgrown by the faster growing Dipterocarps.

40. As the Dalam block of the Lambir Forest Reserve has been gazetted as a Research Forest it is hoped this paper will afford a basis for future comparisons. For the moment re-enumeration of the area of small-sized Sempilor might throw light on its increment since 1952.

BIOGRAPHICAL NOTE OF AUTHOR

T. W. W. WOOD, born 1927, in London, England. Educated in Glasgow, Scotland. B. Sc. degree in Forestry in 1952 from Aberdeen University, Scotland. In 1953 appointed with the Colonial Forest Service, Sarawak. Attended a post-graduate course at the Imperial Forestry Institute, Oxford, in 1956–1957. Studied the coastal forest soils of the Bintulu area. Co-author with Ph.T. Bechett of: Some Sarawak soils of the Bintulu coastal area, 1961.

DISCUSSION

WHITMORE:

The tree species are not reproducing themselves, so what is the forest turning into?

WOOD:

I am not sure, but it is evident that there are only seedlings of *Dacrydium elatum* present as the pole stage is absent.

WEBB:

Is it not possible that only a few seedlings are enough to maintain the composition of this very slow moving vegetation?

WOOD:

This seems unlikely as the number of mature trees is much larger than the number of seedlings.

QURESHI:

Would it be possible to name some plant indicators characterizing the sites suitable for the occurrence of the recognizable forest type and even subtypes?

BRUNIG (on QURESHI):

On the question regarding the use of herbaceous plants as soil indicators in Sungei Dalam Forest Reserve, it appears that a number of plants such as *Eugeissona minor, Mapania petiolata, Licuala bidenta, Pinanga* sp. nov. etc. are useful indicators of the soil conditions within the area. *Nepenthes bicalcarata* as an example indicates wet deep peat.

Pemb. Balai Besar Penjelidikan Pertanian 1951

POT AND FIELD EXPERIMENTS WITH MAIZE ON ACID FOREST PEAT FROM BORNEO

by

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Peat Specialist and Assistant Soil Scientist respectively, Institute for Soil Research, General Agricultural Research Station, Bogor, Indonesia.

INTRODUCTION

Preliminary pot experiments with forest peat from West Borneo made by EHRENCRON (1949) at the Institute for Soil Research proved that these peat soils are so acid and so poor in plant nutrients that it is only possible to obtain well-developed maize plants provided that the acidity of the peat is reduced from pH 3.3 to 5.0-5.5 by liming and the plants receive a complete fertilization with NPK. Copper, which in several parts of the world is known to be beneficial on acid peat soils, gave no response in these experiments.

The pot experiments with maize were continued by the present authors to determine the optimal application of lime and fertilizers. EHRENCRON applied sulphate of ammonium and potassium which have an acid reaction. It would seem desirable to investigate the effect of the application of the alkaline compounds sodium nitrate and potassium carbonate on soil acidity. Moreover, the problem of the minor elements had to be studied more thoroughly.

With a view to practical cultivation, field trials should be conducted to confirm the results obtained in the pot experiments. In Indonesia, however, the peat soils under discussion are far from scientific centres and frequently far from human dwellings. This is a serious drawback in the laying-out and proper control of field plots on these soils. It was therefore necessary to enlist the assistance of the Agricultural Extension Service in West Borneo. The authors are greatly indebted to Mr J. VOORMOLEN and his staff, Messrs J. C. BERENDS and SARIADI, for their kind cooperation under trying circumstances. Due to various factors the data on these field experiments are not as elaborate and accurate as might be desired; they only allow of some general conclusions.

Finally, in this paper some aspects of peat burning are discussed and some initial experiments were made in the laboratory and greenhouse in an attempt to find an explanation for the favourable effect of this peat burning on crop growth.

I. POT EXPERIMENTS

The peat soil used in the pot experiments was collected from two different localities in West Borneo, *viz.*

1. Sumúr Bor (Sungai Bangkong), 4 km S. of Pontianak, where the peat layer is 2-3 m thick, underlain by bluish grey heavy clay, and

2. Sungai Kunjit near Mempawah, about 80 km N. of Pontianak, where the peat deposit is 5-6 m thick, also underlain by blue-grey clay.

Both types of peat belong to the extensive ombrogenous peat complex occurring along the west coast of Borneo (POLAK, 1941). It is easily understood that these thick deposits of forest peat must be extremely poor in plant nutrients. The entire stock of mineral matter originates from the subsoil. Since the rain water washes out soluble matter, the content of plant nutrients in the peat gradually decreases with the increase in the thickness of the deposit. As will be seen from the chemical analyses in table 1, the peat of 5-6 m thickness at Sungai Kunjit is still poorer in plant nutrients than the peat of 2-3 m thickness at Sumur Bor.

TABLE 1. CHEMICAL COMPOSITION OF THE PEAT SAMPLES USED

Origin of peat	In per cent. of dry matter						
	N total	Ash	P_2O_5	K_2O	CaO	MgO	Fe_2O_3
Sumur Bor .	1.80	2.28	0.12	0.10	0.42	0.14	0.63
Sungai Kunjit	1.70	1.73	0.04	0.05	0.51	0.22	0.07

The peat of Sungai Kunjit is the poorest in plant nutrients of all peat soils hitherto known in Indonesia. Especially its very low iron content, already mentioned by EHRENCRON (1949), is most striking.

Starting with a standard fertilization CaNPK, variations were made in the applications of the most important nutrients N and K per pot. The effect of the minor elements Cu, Mn and Mg was compared with the standard; the response to iron was only investigated in the S. Kunjit series.

Our standard fertilization was based on quantities of 11 tons $CaCO_3$ per ha for Sumur Bor and 15 tons per ha for Sungai Kunjit, as well as on 200 kg sodium nitrate, 250 kg double superphosphate and 500 potassium carbonate per ha. As each pot contained 12.5 kg of peat soil, the application per pot was 110-150 g $CaCO_3$, 2.7 g $NaNO_3$, 2.5 g $Ca(H_2PO_4)_2$ and 5 g K_2CO_3. Minor elements were added to the standard quantities of CaNPK at the rate of 0.5 g per pot.

Series of ½ and 1½ times the amount of nitrogen and potassium were started for comparison with the standard fertilization. Moreover, the effect of ammonium sulphate and sodium nitrate in proportional quantities was compared as well as the effect of potassium sulphate in comparison with potassium carbonate (see scheme in table 2).

The lime, in the form of fine powdered $CaCO_3$, was thoroughly mixed with the soil 2-3 weeks before planting. This resulted in a gradual increase in the pH to values above 5.2, as will be seen in table 2. The other nutrients were added in solution shortly before planting.

Madura maize was used in all the experiments. This short maize variety is generally cultivated in the peat districts of West Borneo. Five seedlings were planted in each pot. After two weeks two plants were cut off, after four weeks two more, so that after a month only one maize plant per pot was left. The fresh and air-dry weight of the cuttings was determined.

In the beginning no great differences in plant growth were observed. There was only a slight indication that the acid fertilizers gave a better response than the alkaline ones, which might be ascribed to an overdose of lime. No beneficial effect of minor elements could be established.

Already two weeks after planting a difference between the plants of the Sumur Bor and S. Kunjit series was noticeable. The latter were smaller in size and lighter in colour, the young leaves showing yellow stripes. Neither a beneficial effect of the application of iron nor a larger amount of fertilizer could be detected at that moment. Although in the course of time the stripes gradually vanished, the leaves of the S. Kunjit plants retained a lighter green colour than the Sumur Bor plants.

TABLE 2. AVERAGE WEIGHT OF MAIZE PLANTS OF THE POT EXPERIMENTS

Origin of peat	Objects		pH after 11 weeks	Air-dry weight in g	
				Plant + ear	Ear
Sumur Bor	Ca-N-P-K	N as $NaNO_3$	5.6	42.0	7.7
	Ca-½N-P-K		5.7	32.7	5.2
	Ca-1½N-P-K		5.6	45.0	18.9
	Ca-N-P-K	N as $(NH_4)_2SO_4$	5.5	33.2	3.2
	Ca-½N-P-K		5.6	38.7	13.7
	Ca-1½N-P-K		5.4	47.8	23.5
	Ca-N-P-½K	N as $NaNO_3$	5.6	44.2	12.6
	Ca-N-P-1½K		5.6	46.7	24.7
	Ca-N-P-K	N as $(NH_4)_2SO_4$, K as K_2SO_4	5.4	41.8	8.1
	Ca-N-P-K-Cu	N as $NaNO_3$	5.6	43.7	16.3
	Ca-N-P-K-Mn		5.6	38.4	15.1
	Ca-N-P-K-Mg		5.6	42.6	13.2
S. Kunjit	Ca-N-P-K	N as $NaNO_3$	5.4	34.7	12.3
	Ca-½N-P-K		5.4	31.8	9.7
	Ca-1½N-P-K		5.4	40.6	19.9
	Ca-N-P-½K	N as $NaNO_3$	5.3	32.1	6.1
	Ca-N-P-1½K		5.5	34.7	9.1
	Ca-N-P-K	N as $(NH_4)_2SO_4$, K as K_2SO_4	5.2	57.6	25.6
	Ca-N-P-K-Cu	N as $NaNO_3$	5.4	46.3	22.0
	Ca-N-P-K-Mn		5.3	33.6	9.8
	Ca-N-P-K-Mg		5.3	28.8	1.4
	Ca-N-P-K-Fe		5.2	37.8	12.8

In order to investigate whether iron deficiency played a role in the discolouring in the S. Kunjit series, the leaves were injected with an iron solution according to ROACH and ROBERTS (1945). Where injected the leaves turned dark green, which is a definite proof of iron deficiency. Evidently too little iron was applied to the peat soil. An increased dosage produced a better colour, but none of the objects in either series darkened sufficiently. At first the permanent light green colour was ascribed to the weather, which throughout the experiment was very rainy and cloudy, with only little sunshine. Later on, however, it became evident that in all the objects lack of nitrogen caused the light green colour. The tips of the lower leaves became yellow and dried up, and the whole leaf died off prematurely. A closer examination of photo 2 in EHRENCRON's paper shows the same phenomenon.

Forty days after planting the tassels appeared. At that time the plants that had received the highest amount of nitrogen and those to which copper and magnesia had been applied, had made the most progress.

At maturity the best results were obtained from those objects which received the heaviest application of nitrogen. Ammonium sulphate proved to be more beneficial than sodium nitrate (Table 2).

In both series a dressing of 0.5 g sulphate of copper per pot resulted in a yield twice as large as when no copper was applied. This is contradictory to the results reported by EHRENCRON (1949), who found no response. The amount of copper sulphate in our experiments was 0.5 g per 12.5 kg peat, that is twice the quantity used in the earlier experiments (0.1 g per 5 kg peat). The optimal amount of copper sulphate is open to further investigation.

As already stated, in the S. Kunjit series no response to iron was observed, probably because the dosage of iron was too small. A heavier application of potassium was only beneficial in the Sumur Bor objects.

In nearly all objects the ears were under-developed. The tips of the ears were unfilled and many chaffy nubbins occurred. This may be caused by insufficient pollination due to the limited space in the greenhouse in which the experiments were conducted, but nitrogen or some other deficiency may also be responsible for this deviation.

II. FIELD EXPERIMENTS

The field plots were laid out in the same localities at Sumur Bor and Sungai Kunjit, where the peat soil for the pot experiments was obtained. The original vegetation in these places consists of a dense swamp forest of slender trees, mostly *Calophyllum* and various *Myrtaceae*. The undergrowth is rich in *Nepenthes*. When cleared, the peat is covered with a secondary vegetation of ferns, mostly *Blechnum orientale* L., and scattered groups of *Ficus* scrub.

As already mentioned in the introduction, many difficulties were encountered in the lay-out of the field trials. Not only was the isolated situation a handicap in exercising proper control of the experiments but due to the marked inequality of the peat soil (with many wood remains and patches of wood ash), plant growth even in the individually treated plots was very irregular.

The fertilization scheme adopted in the pot experiments was too complicated to be applied in the field trials. Only the effect of three different applications of lime and the response of the minor elements Cu and Mg (and Fe in Sungai Kunjit) were studied.

The plots, measuring 4 × 7.5 m, were laid out with five or six replications. The distance between the maize plants was 35 × 35 cm.

Sumur Bor series. — The fertilization scheme of the Sumur Bor field (with 5 replications) was as follows:

TABLE 3. FERTILIZATION SCHEME AT SUMUR BOR (IN KG/HA)

Objects	Lime	Ammonium sulphate	Double super-phosphate	Potassium sulphate	Minor elements
A	10,000	200	250	200	—
B	15,000	200	250	200	—
C	15,000	200	250	200	—
D	15,000	200	250	200	50 $CuSO_4$
E	20,000	200	250	200	50 $MgSO_4$

Lime and double superphosphate were applied one month before planting and worked into the soil by simple hand tools. The soil was then stamped with a heavy piece of wood to imitate the rolling of the peat as is the custom in Europe and North America. Potash and nitrogen were applied in two dressings, two and five weeks after sowing respectively, the minor elements in one dressing two weeks after sowing. The highest lime dosage, intended for the C plots, was accidentally given to the E plots; B and C were thus given the same dressing.

The maize was planted on February 15, 1950. All the seeds germinated, but already on March 2 the young seedlings from the A plots turned yellow and were backward.

On March 22 the various plots were checked again by Mr BERENDS. Quite considerable differences were observed within the plots that received an identical amount of fertilizer, undoubtedly due to local inequalities of the peat soil.

The A plots with the lowest lime application showed the poorest growth, with yellowish green plants and much drying up of the lower leaves. The plants in B, C, and E were higher and greener. The D plots treated with copper sulphate excelled in all respects. The plants were twice as high as those in the other objects and much darker in colour (see Fig. 1).

Contrary to the striking effect of copper, the response to magnesium was not conspicuous. Unfortunately the magnesium was applied to the plots E which received the largest amount of lime. It is often stated in literature that Mg is complementary to Ca and that on upland soils a ratio of 1:3 is optimal, but it is still a matter for further investigation whether there is an optimal Mg:Ca ratio on acid peat soils.

The yield of ears from the various plots is shown in table 4. Many ears had sterile tips and even entirely unpollinated ears were observed. This might be attributed to a deficiency of nitrogen or potassium, but an accurate diagnosis of this symptom was impossible due to the difficulty in making regular observations on the spot.

TABLE 4. YIELD OF AIR-DRY EARS AT SUMUR BOR (IN KG)

Objects	Plot number					Average
	1	2	3	4	5	
A	0.10	0.13	0.13	1.30	1.20	0.6 ± 0.37
B	1.50	1.55	1.20	2.35	0.50	1.4 ± 0.26 (B, C)
C	1.05	0.70	1.95	1.45	1.25	
D	4.25	7.05	6.35	7.00	7.85	6.5 ± 0.37
E	1.50	2.75	1.65	1.40	0.70	1.6 ± 0.37

The A plots showed the poorest results; an application of at least 15 tons of lime per hectare seems advisable. The D plots treated with sulphate of copper gave a highly significant increase in yield, approaching 5-6 times that of the other objects.

Sungai Kunjit series. — In view of the peculiar circumstances and the isolated location the records relating to this field trial on very poor peat are still less complete thans those for Sumur Bor.

The size of the plots and the distance between the maize plants were the same as in Sumur Bor. Six different objects were investigated with 6 replications (Table 5).

The quantities of N, P and K fertilizer were equal to those of the Sumur Bor field. As regards the quantity and the mode of application of the iron no accurate data are available.

TABLE 5. FERTILIZATION SCHEME AT SUNGAI KUNJIT (IN KG/HA)

Objects	Lime	Ammonium sulphate	Double super-phosphate	Potassium sulphate	Minor elements
A	10,000	200	250	200	—
B	15,000	200	250	200	—
C	20,000	200	250	200	—
D	15,000	200	250	200	50 $CuSO_4$
E	15,000	200	250	200	50 $MgSO_4$
F	15,000	200	250	200	bog iron concretions

According to the reports from Mr BERENDS, all the plants in the various objects were of a yellowish colour. This unhealthy appearance may be ascribed to a deficiency of nitrogen. A deficiency of iron may also be responsible for the yellow colour. Although no response to iron was observed in the F plots the application of ground iron concretions is not the best way to eliminate a possible iron deficiency.

As in Sumur Bor, the A plots showed the poorest stand and the D plots the best stand, but the effect of the application of copper was less striking than in Sumur Bor field.

Notwithstanding the unfavourable prognostics, the average yield of ears (Table 6) was greater in S. Kunjit than in Sumur Bor, with the exception of those of the copper-treated objects. Nevertheless, even in the S. Kunjit trial the D plots gave a significant increase in yield compared with the A plots.

TABLE 6. YIELD OF AIR-DRY EARS AT SUNGAI KUNJIT (IN KG)

Objects	Plot number						Average mf = 0.35
	1	2	3	4	5	6	
A	2.8	2.3	2.2	3.0	1.7	1.2	2.2
B	3.3	2.3	2.7	3.8	2.7	2.7	2.9
C	*)	5.0	3.2	3.0	2.1	2.7	3.2
D	4.9	4.1	5.0	2.8	4.8	3.7	4.2
E	2.7	2.9	3.5	1.5	4.5	1.9	3.0
F	2.6	*)	3.5	2.4	3.3	*)	3.0

*) These yields were lost in transit.

III. SOME REFLECTIONS ON PEAT BURNING

In all parts of the world the initial stage of reclamation of low-lime peat soil consisted in a burning of the upper layers. After drainage and consequently drying up of the surface, the vegetation is fired, and because of the combustible nature of the soil, a layer of peat ash is produced underlain by carbonized peat. The underlying substratum is subject to considerable heat. It was stated by KELLEY and McGEORGE (1913) that burning a brushwood on upland soil in Hawaii resulted in a rise in temperature of the soil of about 200° C. It is a well-known fact that heating of soils often produces a significant increase in fertility, sometimes due to changes in chemical composition of the soil, sometimes due to sterilization and elimination of injurious soil micro-organisms.

Peat burning was practised until some 50-100 years ago in the Netherlands (Province of Drente), but was abandoned and substituted by the so-called Dutch fen method, entirely based on the use of artificial fertilizers. In Indonesia burning is still the only method to reclaim peat.

Visiting the peat areas of Western Borneo where no fertilizer whatever is used, one is struck by the fact that crops, although very irregular in growth and yield, are not so deficient in nitrogen as our pot experiments showed. Maize seeds are planted in a hole filled with ash, thus providing the mineral matter necessary for the growing plant. But still, where does nitrogen come from, so badly needed by maize?

In the days when peat burning was still practised in Western Europe, but at the beginning of a new era, FLEISCHER (1891) and ELEMA (1909) summarized the advantages and disadvantages of peat burning. It was considered an advantage that nitrogen incorporated in the organic compounds was liberated in the form of ammonia and that phosphorus became more readily available, while potassium accumulated in the ash. After a period of burning, however, the peat should be left to regenerate for some 20 years. Since burning eats away the upper layer, the disadvantage is that the surface of the land is gradually lowered and drainage impeded.

In order to investigate whether heating of the peat itself does indeed produce ammoniated nitrogen, we made some preliminary experiments.

Moist peat soil was placed in a glass beaker and heated in an

Fig. 1. Field trial at Sumur Bor. Contrast between an A plot with the lowest lime application in the foreground, and two D plots with more lime and copper sulphate on the left and right in the background.

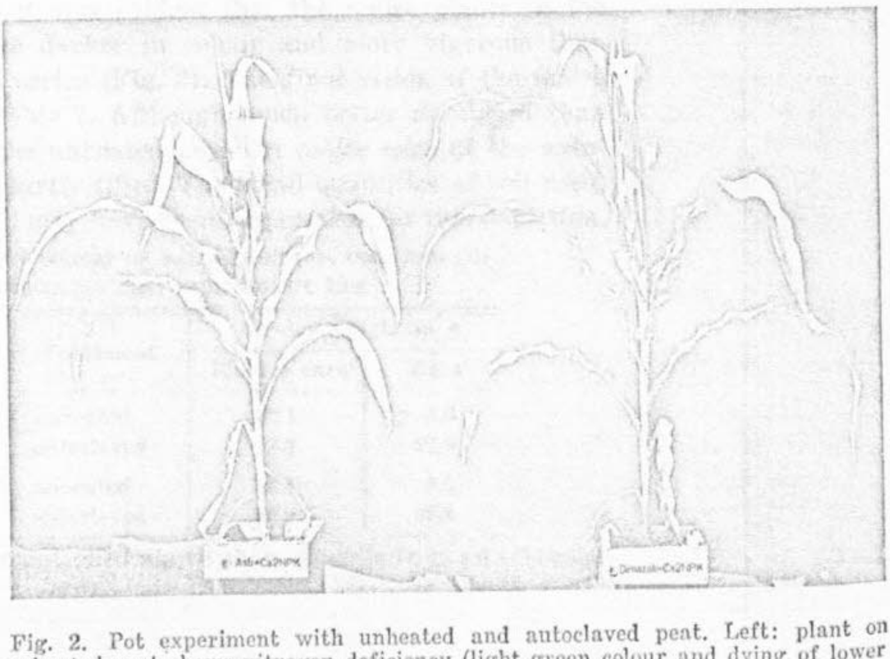

Fig. 2. Pot experiment with unheated and autoclaved peat. Left: plant on unheated peat shows nitrogen deficiency (light green colour and dying of lower leaves). Right: plant on autoclaved peat is healthier and darker in colour.

electric oven at a temperature of 105° C. Ammonia-freed air was conducted through the peat and then through NESSLER reagent. After about three hours the reagent became turbid, whereas applied to unheated peat not the slightest turbidity occurred. In another experiment the air was conducted through 0.1 *N* sulphuric acid. Starting with about 100 g moist peat, after 6 hours 1 mg ammonia could be determined in the solution.

These simple tests demonstrate the liberation of ammonia in measurable quantities by heating. The supposition that micro-organisms play a role after such a short time seems irrevalent.

The next pot experiment was made to ascertain whether the liberated nitrogen in heated peat soil has any effect on plant growth.

Unglazed earthenware jars, containing 5 kg of moist peat soil from Sumur Bor, were autoclaved at 128° C for 2½ hours. The peat was subsequently limed in the same way as in the previous pot experiments. For comparison unheated peat was similarly treated with lime and lime + NPK. Maize (Madura variety) was planted in both series.

The unheated peat proved to contain 3 ppm NO_3 and 9 ppm NH_3, the autoclaved peat 2.5 ppm NO_3 and 18.5 ppm NH_3 in MORGAN analysis. In the autoclaved peat the pH value increased from 3.2 to 3.5, and after liming to 4.8, whereas in the unheated peat series a final pH of 4.5 was attained.

After two weeks it was evident that the maize plants in the autoclaved series were darker in colour and more vigorous than those in the unheated series (Fig. 2). The final yields of the maize plants are shown in table 7. Although much better developed than those collected from the unheated pots the maize ears of the autoclaved pots were still partly filled. The small quantities of soil used, due to lack of material, may have been responsible for this deviation.

TABLE 7. AIR-DRY WEIGHT OF MAIZE PLANTS ON UNHEATED AND AUTOCLAVED PEAT FROM SUMUR BOR

Objects	Treatment	Air-dry weight in g	
		Plant + ears	Ears
Ca	unheated	30.1	8.0
	autoclaved	53.7	27.6
CaNPK	unheated	42.1	7.5
	autoclaved	82.9	42.8

The experiments mentioned above show that there is an increase in available nitrogen in heated peat which enhanced crop growth. Burning of peat soil is likewise advantageous, as nitrogen is liberated in the underlying heated layer; moreover, it produces mineral matter in the ash.

Taking into consideration the consequences of peat burning, a combination of this method with supply of artificial fertilizers is suggested. In forest peat reclamation in Indonesia, at least one burning is indispensible to clear stump and wood remains to adapt the land for agricultural purposes. When the ash is spread evenly over the field it should be determined whether the acidity of the peat has decreased sufficiently, otherwise an adequate amount of lime should be added. After the first maize crop it is recommendable to sow a legume from inoculated seed. This crop should be worked into the soil to provide nitrogen and nitrifying organisms. It is a matter for further experimentation whether nitrogenous fertilizer will be necessary for the second crop of maize, but it can at least be expected that far less is needed than when no burning followed by green manuring has taken place.

When maize and a leguminous crop are grown in rotation regularly and controlled peat-burning is practised occasionally, the need for an artificial nitrogenous fertilizer may be considerably less and an appreciable saving in expenditure can be achieved. An application of copper to the green manure crop should, however, not be omitted.

Field trials should prove what quantities of supplementary NPK fertilizer and lime are still required. In view of the heavy rainfall and considerable leaching of mineral matter, copper should be applied in larger quantities thans necessary under temperate climatic conditions.

SUMMARY

1. Nitrogen has proved to be the most important fertilizer for acid forest peat soils in West Borneo. It should be applied to maize at a rate exceeding 200 kg ammonium sulphate per hectare. The supply of lime should not be less than 15 tons/ha in the first year.

2. Without application of sufficient nitrogen the proper response to other nutrients cannot be established.

3. In pot and field experiments a very distinct benefit from the application of at least 50 kg/ha copper sulphate was found.

4. Heating of peat soil to 105 - 128°C results in a liberation of ammonia, to which the maize crop showed a marked response.

5. Controlled peat burning is recommended in combination with green manuring and supplementary artificial fertilizing. A considerable saving in expenditure for reclamation of acid forest peat soils can thus be achieved. Further field trials will, however, be necessary to establish the most favourable management.

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Pertjobaan-pertjobaan dipot dan diluar dengan Djagung atas tanah rawang hutan masam dari Kalimantan

oleh

Dr B. POLAK dan M. SUPRAPTOHARDJO.

(*Singkatan*)

Pertjobaan-pertjobaan jang dibentangkan dalam risalah ini adalah landjutan penjelidikan EHRENCRON mengenai penanaman djagung di tanah rawang Sumur Bor dan Sungai Kunjit. Tanah rawang ini adalah sebagian dari tanah rawang hutan masam jang meliputi seluruh pantai barat Kalimantan. Tanah rawang ini adalah miskin sekali tentang zat-zat makanan (daftar 1).

I. *Pertjobaan-pot.* Dari pertjobaan tahun 1949 telah terbukti, bahwa hanja pemupukan dengan CaNPK sahadja dapat menghasilkan tanaman jang sempurna. Maka sekarang ini hendak diselidiki dalam djumlah manakah N dan K itu dapat diberikan (daftar 2), serta mengetahui sedjauh manakah pupuk-pupuk alkali lebih baik dari pada pupuk-pupuk masam ($NaNO_3$ lawan $(NH_4)_2SO_4$ dan K_2CO_3 lawan K_2SO_4), dan bagaimanakah dajanja unsur-unsur mikro Cu, Mg, Mn dan Fe.

Pada pertjobaan-pertjobaan kami ini pada umumnja tampak warna kekuning-kuningan pada semua tanaman. Dalam hal ini seri Sungai Kunjit memperlihatkan warna jang lebih kuning disertai dengan pengawakan tanaman jang kurang baik.

Disamping jang tersebut tadi masih tampak pula gezala kering pada putjuk-putjuk daun. Gezala ini adalah disebabkan karena kekurangan N. Selandjutnja dapat dikemukakan, bahwa pemberian N jang paling tinggi, ja'ni 1½ N, jang sesuai dengan pemberian 200 kg za/ha, adalah masih rendah (daftar 2).

Kekurangan N mengakibatkan, bahwa daja pupuk-pupuk lain tidak dapat tampak djelas; dengan perkataan lain kekurangan N mengaburkan daja pupuk-pupuk lain. Daja pupuk masam tampak disini agak lebih baik daripada pupuk alkalis, ja'ni jang disebabkan pemberian kapur jang agak terlalu banjak.

Disamping kekurangan N seperti jang tersebut diatas, maka seri Sungai Kunjit masih memperlihatkan gezala garis-garis kuning pada daun jang berdjadi pada djagung jang belum satu bulan umurnja. Injeksi pada daun dengan $FeCl_3$ menurut tjara-tjara ROACH dan ROBERTS (1945), memberikan hasil jang positip, maka dapatlah dipastikan, bahwa gezala tersebut adalah disebabkan oleh kekurangan besi (Fe).

Pertjobaan kami dengan tembaga (Cu) dan pemupukan lengkap menampakkan daja jang bagus, lebih-lebih daja tersebut dapat dibuktikan dengan djelas dalam pertjobaan diluar. Daja unsur-unsur mikro jang lainnja tidak memberikan gambaran jang djelas.

II. *Pertjobaan diluar.* Pertjobaan ini deselenggarakan ditempat pengambilan tanah rawang untuk pertjobaan dipot itu. Jang diselidiki disini ialah pengaruh pemberian kapur dalam tiga tingkat dan pengaruh unsur-unsur mikro (daftar 3 dan 5).

Terbuktilah disini, bahwa pemupukan dengan 150 q/ha untuk Sumur Bor dan 200 q/ha kalsiumkarbonat untuk Sungai Kunjit memberikan hasil-hasil jang paling bagus. Dengan djelas tampak kelebihan hasil dari tembaga (daftar 4 dan 6, gambar 1).

III. *Pembakaran tanah rawang.* Pembakaran ini adalah satu-satunja tjara di Indonesia terhadap rawang untuk menjediakan zat-zat makanan. Oleh karena itu kekurangan N diluar tampak tidak begitu banjak daripada dipertjobaan dipot.

Hal ini tidak lain harus disebabkan oleh panas jang ditimbulkan oleh pembakaran, jang dapat membebaskan dari persenjawaan-persenjawaan organis zat nitrogen jang dapat dihisap oleh tanaman (FLEISCHER, 1891 dan ELEMA, 1909).

Penjelidikan jang dilakukan oleh kami dapat menentukan, bahwa ammoniak terbukti bebas. Sesudahnja pot-pot dengan tanah rawang dipanaskan dalam autoclaaf pada 128°C selama 2½ djam, maka terus ditanami dan sebagian dipupuk (daftar 7). Pot-pot dengan tanah jang dipanaskan memperlihatkan tanaman-tanaman jang bagus dan kuat. Djelaslah, bahwa persediaan N adalah lebih bagus, lagipula persediaan zat² mineral lainnja bertambah (Gambar 2).

Mengingat kepada akibat-akibat pembakaran tanah gambut itu, maka dapatlah diandjurkan disini sbb.: Pembakaran lapisan atas tanah rawang hendaknja didjalankan dengan seksama dan dengan teratur. Sesudah abu ditjampur ditanah sampai rata, perlu kiranja diperiksa kemasamannja agar kapur dapat diberikan menurut setjukupnja. Kemudian ditebarkanlah benih pupuk hidjau jang terlebih dahulu diberi bibit bakteri. Pupuk hidjau itu kelak dikuburkan kedalam tanah. Sesudah itu barulah djagung itu ditanamkan. Dengan djalan begitu dapatlah diharapkan penurunan ongkos-ongkos mengenai pemupukan N. Betapa banjak djumlah kapur jang diperlukan dan berapa banjak pupuk buatan jang perlu ditambalkan, haruslah ditentukan dalam pertjobaan-pertjobaan diluar.

Cond. Gen. Agric. Res. Station, Bogor (No Maps.

PREFACE

About thirty years ago the problem of the tidal swamps, the so-called "rapaks", in South Borneo was first brought to the attention of the Institute for Soil Research.

The rice shortage in Indonesia during and immediately after the first World War made it desirable to stimulate the cultivation of rice in the various undeveloped areas outside Java. In view of the shortage of labour in these areas mechanized cultivation was considered, and one of the areas selected for this purpose was the tidal swamp region along the south coast of Borneo. The first investigations into the soil conditions in these swamps were carried out by W. H. E. SCHREUDER, agricultural adviser attached to the Institute for Soil Research.

These preliminary investigations already revealed the fact that part of these swamps can be made suitable for rice cultivation; the methods to be applied, however, will differ quite substantially from those used in Java for instance. On account of the high water level it was necessary to resort to a type of swamp rice cultivation already practised on a small scale by the autochthonous population. As this system of cultivation is practised mainly by Bandjarese farmers, it is known as the Bandjarese rice cultivation. They grow late-maturing varieties (8-10 months) which have to be transplanted several times.

Although this swamp cultivation was gradually extended during the thirties, the rice crops did not always prove to be satisfactory. There were many failures which were attributed to inadequate drainage and insufficient supply of fresh water. Investigations carried out in these areas by the soil scientist J. W. VAN DIJK in 1936 showed that rice cultivation on these flooded swamps is dependent on very special hydrological and pedological conditions. In reclaiming the land a gradual humification of the originally peaty and highly acid forest humus should be the first objective. A further complication was the presence of a subsoil rich in sulphides. Inefficient drainage causes oxidation of these sulphides to water-soluble iron and aluminium sulphates which in certain concentrations have a highly poisonous effect on rice.

The report of VAN DIJK led to a more systematic soil survey of the tidal swamps in 1937, on this occasion in connection with the transmigration of Javanese farmers.

The junior soil scientist C. L. VAN WIJK was charged with this survey. During the dry seasons of 1938, 1939, and 1940 he explored thoroughly the tidal area, especially that part between the rivers Barito and Kahajan. All those acqainted with these almost inaccessible swamps will appreciate that VAN WIJK's task was no easy one. Nevertheless his commission was crowned with success. He collected over 1000 soil samples and about 125 water samples which he brought back to Bogor for further investigation. His findings were recorded in a number of notes and reports but owing to the war in the Pacific there was no opportunity to publish the results of his work.

After the war the question of reclaiming the tidal region again came up for discussion. Dr H. J. SCHOPHUYS recently drew up a gigantic plan for the contruction of canals and dikes, which is at present under discussion by the relevant Ministries.

Though this plan, which comprises a pumping system to control both the intake and the outlet of water, offers a far wider scope for agriculture than did the pre-war reclamation plans for a more or less primitive swamp rice cultivation, the minute investigation of VAN WIJK has retained its full value, so that a recapitulation of the results he obtained was essential.

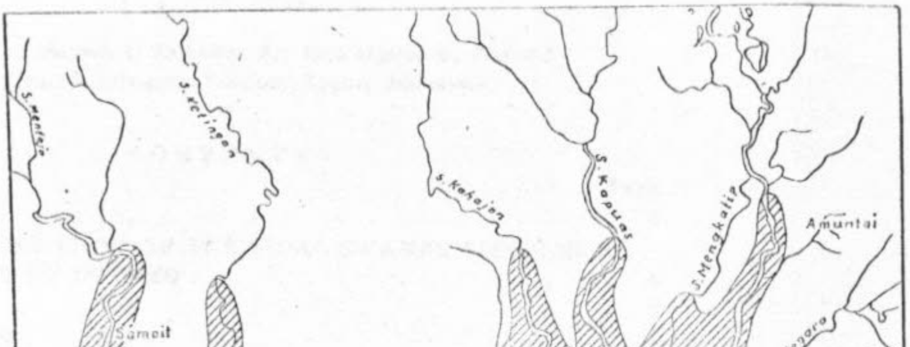
This summary has therefore been drawn up by the present writer in cooperation with VAN WIJK. From the great number of laboratory figures some typical soil and water analyses were selected and tabulated. The vegetation map drawn by VAN WIJK was checked and, where necessary, supplemented by means of more recent aerial photographs.

VAN WIJK's investigation is of great importance not only for the agricultural development of the area near Bandjarmasin, but also for the reclamation of many other coastal plains in Indonesia where similar water and soil conditions prevail.

Bogor, November 1950.

M. VAN DER VOORT,
Head of the Institute for Soil Research.

GENERAL MAP OF THE TIDAL SWAMPS OF S.BORNEO



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SOIL SURVEY OF THE TIDAL SWAMPS OF SOUTH BORNEO IN CONNECTION WITH THE AGRICULTURAL POSSIBILITIES

by

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CONTENTS

INTRODUCTION

Within the framework of the comprehensive exploration work carried out before the war by the Institute for Soil Research in the interest of the transmigration of part of the population of Java and Madura to the other islands, during the years 1938-1941 an investigation was made into the land and soil conditions of the tidal plain along the south coast of Borneo.

The object of this investigation carried out by the writer was to determine — by means of an accurate local study — the special soil and agricultural conditions necessitated by the characteristic "sawah bajar", or swamp rice cultivation, practised by the local population, and subsequently to ascertain by means of a soil survey the extent to which the existing swamp rice fields might be extended in the interest of the future colonization of Javanese in this area.

Owing to the permanent swampy conditions prevailing in this tidal region between the Sungei (River) Barito and S. Mentaja, the usual method of soil surveying could not be employed. The inaccessibility of the land and the high ground-water level restricted the possibility of establishing the nature and distribution of the soil types present in this area.

Preliminary investigations showed, however, that a method of floristic surveying could be carried out successfully in this swampy area. The boundaries of certain clearly distinguishable types of vegetation namely were found to coincide with those of organogenic formations, the characteristics of which in turn correlated with certain soil properties, such as acidity and content of certain components injurious to crops.

The floristic survey will be explained in detail below by means of the appended vegetation map of the area between the S. Kahajan and the S. Barito, which proved to offer the widest scope for the object in view.

In addition, important data were collected concerning the properties of the soil and the ground-water in some localities in the neighbourhood of Bandjarmasin already occupied by the local population. These data form an indispensable basis for further considerations regarding the agricultural possibilities of the hitherto uncultivated areas in this swamp region.

I. Natural conditions of the tidal swamps along the south coast of Borneo

Origin. — The tidal area investigated forms part of the alluvial coastal plain which stretches along the entire south coast of Borneo, gradually widening in an easterly direction. A few low divides, running from north to south, split this coastal plain into a number of smaller plains which, when viewed from west to east, constitute part of the respective river basins of the Sungai Arut and S. Kumai, the S. Serujan, the S. Mentaja, and the S. Ketingan. By far the largest area is taken up by the eastern plain which forms part of the river basin of the S. Kahajan (Great Dyak river), the S. Kapuas (Small Dyak river) and the S. Barito with its affluents. No divides were observed between these rivers.

According to MOLENGRAAFF (1922), this coastal plain should be regarded as a relic of the Sunda peneplain which after the Pleistocene glaciation was submerged and later on gradually filled in by deposits from the pre-Tertiary and Tertiary formations in Central Borneo.

More recent geological investigations (VAN DER VLERK and LEUPOLD, 1931) have shown that the eastern part of the plain has been formed out of the so-called Barito Basin, a geosynclinal coastal bay, in which the S. Barito, S. Kapuas and S. Kahajan have deposited their silt. This sedimentation first kept pace with a gradual and slow subsidence of the land. The uplift of this region did not occur until after the regression of the sea during the Pleistocene period. The marine basin was filled in and became a tidal marsh, on which a halophytic vegetation developed. This vegetation held the mud and, together with the erratic currents, greatly influenced the formation of heterogeneous silt deposits.

The final stage of development was reached under the influence of a marine transgression after the Pleistocene glaciation. Thus the characteristic estuaries were formed, and the rivers were unable to discharge freely into the sea. Far inland extensive inundation plains were formed, in which the river silt was deposited, thus raising the area above flood level and at the same time giving the landscape its present morphological shape.

Morphology. — The landscape of these lowlands is determined by fluviatile phenomena.

Where the rivers reach the lowlands, they constantly overflow their banks during the rainy season. As a result of the slowing down of the flow, the coarse particles in the river water are deposited on the banks, thus forming sandy levees. The finer particles are only deposited further downstream. The natural levees (pematangs) along this part of the river are, therefore, more of a clayey consistency.

At right angles to the stream a decreasing sedimentation of finer particles occurs, so that, starting from the river, the land slopes very slightly, forming a faint depression between two rivers.

In the tidal region along the lower course of the rivers the land gradually flattens owing to the considerable losses of silt upstream, so that it can often only be inferred from the hydrological relations that the river banks are slightly higher than the land beyond.

Hydrology. — Where the rivers flow into the Java Sea they form wide estuaries. They are all characterized by a very slight slope; consequently the tidal action makes itself clearly felt about a hunderd kilometres upstream. The tidal region comprises that part of the coastal plain where inundation and drainage are determined by the tidal fluctuations of the river-water level.

In this connection it should be pointed out that in the areas between the rivers the effect of this tidal action is only noticeable when the discharging capacity of the numerous narrow and winding creeks draining the land is increased. A similar effect is achieved when the surplus surface water is discharged into the river by means of a system of canals. The Serapat canal between the S. Barito and S. Kapuas, and the Klampan canal, connecting the S. Kapuas and the S. Kahajan, prove that the tidal action may be utilized to effectuate a strong water movement as far as the centre of the swamp areas.

As the river water flows over the enormous swamps in the hinterland, the danger of flooding in the tidal region is only of minor importance (SCHOPHUYS, 1936). The floods (bandjirs) are only evident along the northern and eastern borders of the tidal region. Thus the areas east of the Barito are to some extent affected by the floods of the S. Negara and S. Martapura. The same effect is caused by "bandjirs" in the Barito upstream from its confluence with the S. Negara, and in the S. Murung above the point where it meets the S. Mengkatip.

As the land along the S. Terusan which anastomosis has hardly any levees, is very low, the river can freely overflow its banks throughout the year at high tide. The same applies to the area along the sea on either side of the mouth of the Barito. During the dry season the ground- and surface water becomes saline here. In the area investigated the brackish-water line is about 8 km from the coast. During the rainy season this line shifts towards the coast.

In the swamps west of the S. Kahajan many low quartz sand ridges are found. These ridges will make it more difficult to drain this area than that east of the river.

Rainfall. — The lowland plain of South Borneo belongs to the area of the rain types 43 and 44 (BOEREMA, 1926), for which the following average monthly rainfall figures were calculated over a number of years.

TABLE 1. AVERAGE MONTHLY RAINFALL IN MM IN THE LOWLAND PLAIN OF SOUTH BORNEO.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
TYPE 43													
Sampit	307	265	275	293	244	189	123	104	134	184	227	274	2621
Kuala Pembuang	212	239	245	259	274	183	156	100	92	255	198	225	2458
Pangkalan Bon	224	201	278	293	235	201	132	121	153	209	217	274	2538
TYPE 44													
Bandjarmasin	321	304	297	221	160	142	95	83	96	132	216	321	2388
Marabahan	305	272	294	222	171	106	59	49	83	106	201	280	2148
Kuala Kapuas	323	272	339	266	128	110	54	52	73	130	219	265	2231

Rain type 43 which is predominant in the west, shows a considerable rainfall even during the period of minimum rainfall, so that no actual dry season can be said to occur here.

Rain type 44 which prevails in the east, shows a period of heavy rainfall during the months of December to May and a more or less dry period of at least three months (July, August and September).

The latter rain type, with a distinctly dry period, should be regarded as more favourable for the ripening of rice crops than that predominating in the west.

Vegetation.

A. O r i g i n a l v e g e t a t i o n s. — In these naturally swampy areas a climax vegetation of swamp and peat forest was formed.

The swamp forest, like the lowland forest on dry soil, is heterogeneous in composition. It consists, however, of other tree species and on the whole has fewer species, since the exceptional growing conditions have a marked selecting effect. The root system has to be specially adapted to the soft, acid and anaerobic milieu. Trees with stilt roots and aerial roots are predominant here. The high acidity of soil and water, together with the oxygen deficiency caused by the permanent waterlogged conditions, impede the decomposition of the abundant quantities of plant detritus, as a result of which organic layers develop under the swamp forest, which layers become thicker as the hydrological conditions in the swamp deteriorate.

As the swamp forest is to a considerable extent rooted in the mineral soil, the organic layer receives a continuous supply of mineral substances in the litter. The thickest peat layers are thus obviously found where no water movement occurs, i.e. in areas far beyond the tidal action and receiving their water supply by means of rainfall only.

Since the younger forest generations can no longer take root in the mineral subsoil, in the long run only a vegetation can maintain itself, which is more and more adapted to the acidifying organic milieu which becomes increasingly poor in bases.

This peat forest vegetation shows the same oecological characteristics at the swamp forest. Here natural selection is even more evident, so that the composition of the peat forest is still less diverse than that of the swamp forest. In the tidal region peat forests on thick peat layers have remained intact only in the area west of the S. Kahajan. East of this river the predominant primeval vegetation is the swamp forest type (see vegetation map legend: No. 1). In the course of soil surveying the peat layer in the South Serapat area was found to have an average thickness in waterlogged condition of only 1.50 m, whereas in the North Separat area at the end of the severe dry east monsoon in 1940 the depth of the peat layer was rarely more than 1 m. In the centre of the swamp between the S. Kapuas and the S. Kahajan the peat layer is thicker, varying from 1.50 to 2.00 m.

B. Vegetations induced by recurrent fires.— Owing to frequent big fires during the dry season the primeval forest vegetation of this swamp region has receded more and more to the permanently inundated areas where the fires could not spread any further.

In the burned areas secondary vegetations developed, in which several stages may be distinguished, ranging from open grass plains to old and dense galam (*Melaleuca leucadendron*) forests.

The initial stage in revegetation consists mainly of sedges (*Cyperaceae*), reeds (*Phragmites karka*) and ferns (leg.: No. 9, see Fig. 1). This vegetation type covers extensive areas on either side

Fig. 1. Deep swamp in South Terusan area, covered with reeds and sedges (vegetation type 9).

Fig. 2. Old galam forest (Melaleuca leucadendron) with climbing ferns (Stenochlaena palustris) on the trunks and undergrowth of Susum malayanum (vegetation type 5).

Fig. 3. Old galam forest with scanty undergrowth and acid surface water (vegetation type 6).

Fig. 4. Very dense galam forest (vegetation type 4).

of the S. Terusan, in the area south of the Klampan canal and between the S. Alalak and S. Negara.

The principal pioneer plants of the secondary forest are the galam (*Melaleuca leucadendron*), pulantan (*Alstonia pneumatophora*) and terantang (*Campnosperma macrophylla*).

The main part of the secondary vegetations, however, consists in the long run of the fire-resistant galam forest. Several sub-stages can be distinguished here, the origin of which is closely related to the frequency and intensity of the fires. Their organic deposits vary in thickness and in composition, as remains of the original swamp forest vegetation are often still found.

The least devastated by the fires are the galam forests which are to a certain extent mixed with mahang trees (*Macaranga triloba*) and have an abundant undergrowth of *Cyperaceae, Phragmites* and ferns (leg.: No. 7). Here the organic layer consists partly of fragments of the swamp forest vegetation, partly of detritus of the new vegetation.

The galam type covering the largest area consists of old galam forest, understoried by rank growth of sedges, reeds and ferns (leg.: No. 5, see Fig. 2). The organic layer is relatively thin and consists mainly of detritus of the secondary vegetation, mixed with some charcoal and plant ash.

In the areas immediately behind the levees, which dry up every year, the effects of the fires are most pronounced. These areas are covered with old galam forests with an extremely scanty undergrowth (leg.: No. 6, see Fig. 3). An organic layer is practically non-existent; it is substituted by a crumbly layer of burned material, which is in sharp contrast to the mineral soil hardened by fire.

A similar subtype is represented by young, very densely growing galam forests without any undergrowth (leg.: No. 4, see Fig. 4). Here too the mineral soil has been hardened by the fires and no organic layer occurs.

The low-lying lands with deep surface water in the southern part of the Terusan area, finally, are characterized by scanty galam vegetations with an undergrowth of rushes (*Lepironia* spec., *Heleocharis fistulosa, Fimbristylis* spec.), bakung or djungkal (*Susum malayanum*) and kumpai or floating grass mats (leg.: No. 8).

C. B r a c k i s h - w a t e r v e g e t a t i o n s. — In the vegetations of the brackish-water zone the nipah (*Nipa fruticans*) predominates. This palm may undoubtedly be considered the best indicator of the presence of brackish water. Along the estuaries dense nipah complexes are found (leg.: No. 10), which further inland are replaced by a dense vegetation of prupuk (*Phragmites karka*) and mangrove ferns (*Acrostichum aureum*) with patches of nipah (leg.: No. 12), or by galam complexes with an undergrowth of nipah and mangrove ferns (leg.: No. 11). In these brackish-water vegetations no organic formations of any significance are found.

D. Dry lowland vegetations are found within the tidal region only in narrow strips on the levees and on a few quartz sand ridges (leg.: Nos. 13 and 14).

The above-mentioned vegetation types were only mapped in the tidal area between the S. Barito and S. Kahajan. The vegetation of the area between the S. Alalak and S. Negara, east of the S. Barito, is rather similar, but here the swamp forest has receded even further than in the area between the two first-mentioned rivers. In the western part of the tidal region the fire-resistant galam vegetations are on the whole far less predominant than in the areas east of the S. Kahajan. It is hard to say which of the three factors: anthropogenic influences, unfavourable hydrological conditions or poor soil composition, has had the greatest influence.

II. Soil conditions

General considerations. — The alluvium in the tidal region has been built up from very fine river silt deposited along the extreme lower course of the rivers, where the stream flows slowly. Consequently the sediments of the various rivers vary only very slightly in granular composition. The content of sand particles larger than 0.05 mm. is always low. Only near the estuaries of the S. Murung have a few ridges richer in sand been found, possibly representing former beach banks.

The mineralogical analyses of the sand fractions carried out on a number of soil samples from the tidal region show that, for the greater part, this sand consists of "old" quartz grains and iron concretions (cf. Table 2). The percentage of quartz was found to increase to the west, whereas the content of iron concretions decreased in that direction. Moreover, the sediments of the western rivers contain slightly more acid feldspars (orthoclase and oligoclase) and micas (muscovite and biotite), together with a few grains of tourmaline, zircone, epidote, and glaucophane.

TABLE 2. MEAN MINERALOGICAL COMPOSITION OF THE SAND FRACTIONS OF SOME SOIL SAMPLES FROM THE TIDAL PLAIN OF SOUTH BORNEO (IN PER CENT. OF TOTAL SAND).

Origin (and number) of soil samples / Soil minerals	Alalak + Kahajan (8)	North + South Serapat (5)	Terusan Kahajan Klampan (5)	Sebangau (2)	Ketingan (7)	Mentaja (9)
Tourmaline	—	—	tr.	tr.	tr.	tr.
Zircone	tr.	tr.	tr.	tr.	tr.	tr.
Epidote	—	—	1	tr.	2	1
Glaucophane	—	—	tr.	tr.	tr.	tr.
Green hornblende	tr.	tr.	tr.	tr.	2	1
Orthoclase	tr.	tr.	2	1	6	4
Acid plagioclase	tr.	tr.	7	—	1	1
Intermediary plagioclase	tr.	tr.	—	—	—	—
"Old" (turbid) quartz	23	17	53	58	57	47
Organic silica	6	1	5	11	2	3
Volcanic glass	tr.	tr.	—	—	—	—
Muscovite	tr.	tr.	1	3	6	2
Biotite	tr.	tr.	1	tr.	5	2
Nontronite	5	2	—	13	—	7
Hydrargillite	—	tr.	1	—	2	2
Iron concretions	32	43	20	7	12	20
Rock fragments	1	tr.	6	tr.	1	1
Other components (mostly organic material)	23	35	3	7	4	9

tr. = traces, less than one per cent.

The difference in mineralogical composition between the sediments of the Barito and those of the western rivers can be explained by the different petrological composition of the hinterland. The upstream drainage basins of the western rivers include not only the Schwaner Mountains built up mainly of granites and other acid eruptive rocks but also a broad strip of Tertiary hilly country built up mainly of quartz sandstones. The high iron content of the Barito sediments is probably due to the occurrence of a few intrusions of basic rocks (peridotite, gabbro, diabase, and andesite) in the Upper Barito Basin and the Meratus Mountains.

As a source of plant nutrients these mineral combinations are of no significance. The minerals are almost without exception hard-weathering and are, moreover, only present in very small quantities.

Although, on the whole, there is no difference in granular composition between the soils of the river levees (tanah pematang and tanah rantjah) and the swampy soils at greater distances from the rivers (tanah baru), they nevertheless differ greatly in organic matter content. In the swamps, where the hydrological conditions are unfavourable, there is a considerable accumulation of plant residue, with the result that peaty top soils or even pure peat layers have developed under primeval vegetation. The anaerobic conditions giving rise to the accumulation of organic matter, also affect the mineral soil. The iron present is converted into the ferrous form and consequently washed out very easily. This leaching process is further accelerated by the presence of unsaturated humic acids which in the lime-deficient milieu are formed as a product of the incomplete oxidation. As a result thereof the mineral soil becomes pale grey in colour.

Careful attention should be given to the chemical processes taking place in the humous marine subsoil of the eastern tidal region. This marine clay is characterized by a high sulphide content, which creates special conditions from an agricultural point of view and will be discussed later.

Inorganic sediments.

a. The r i v e r l e v e e s o i l s in the tidal region with its very flattened landscape occupy only a small area as compared with that taken up by the swamps. The width of the levees ranges from a few hundred metres to about 1½ km. The profile of these levee soils is usually characterized by a grey-brown, somewhat humous, plastic silty clay or clay top soil and a grey, rusty-brown veined, sticky clay subsoil, poor in humus.

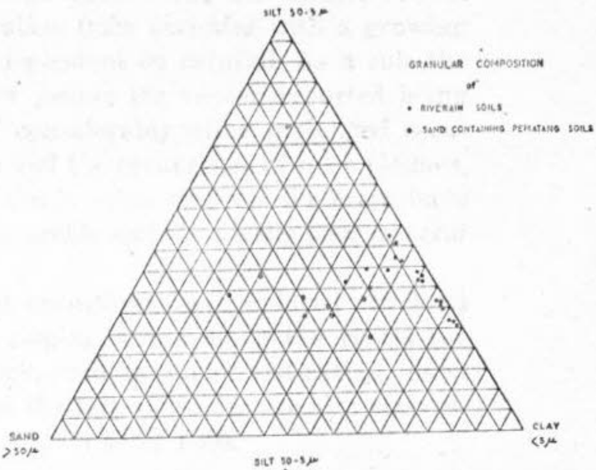
As drainage and aeration on the faintly sloping levees are relatively favourable, the humous top soil is only 10 to 30 cm thick, its organic matter content averaging 10 per cent. and rarely exceeding 20 per cent. This top soil can be satisfactorily tilled, whether wet or dry. The quartz-clay subsoil, on the other hand, is hard when dry. In a moist condition it is sticky, and its margin of tillability is not wide.

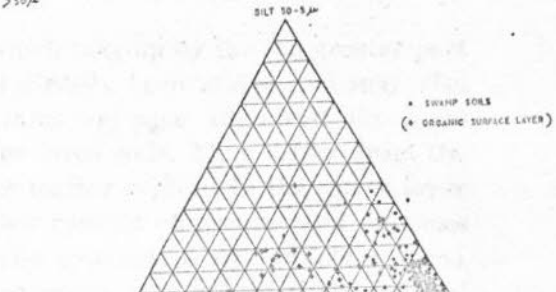
Although these soils are rejuvenated regularly by intermittent inundations and have only been slightly leached by acid swamp water, they nevertheless have a highly unsaturated character. The samples have a pH in water suspension of 3.8-4.6 (cf. Table 3). They are generally remarkably poor in lime (0.007-0.140% CaO soluble in 25 per cent. hydrochloric acid). The magnesia content is usually slightly higher (0.037-0.228% MgO). The phosphorus content varies considerably, depending on the percentage of organic matter; the mineral subsoil, however, is always poor in phosphate (0.006-0.030% P_2O_5). The potash content appears in most cases to be just sufficient (0.010-0.031% K_2O), owing to the small reserves of potash feldspars and biotite already mentioned and mainly found in the western sediments.

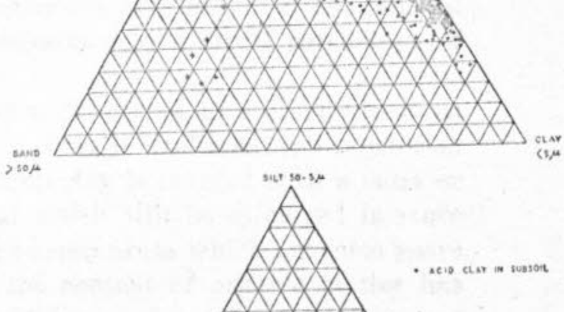
TABLE 3. CHEMICAL COMPOSITION OF SOME RIVER LEVEE SOILS.

Soil sample No.	Depth of sampling cm	Organic matter (Dennstedt) %	N (Kjeldahl) %	Soluble in 25 per cent. HCl				pH
				P_2O_5 %	K_2O %	CaO %	MgO %	
Alalak area								
73037	30	6.62	0.171	0.023	0.018	0.042	0.076	4.3
73054	20	7.79	0.331	0.017	0.021	0.079	0.115	4.6
73055	50	2.84	0.076	0.016	0.027	0,095	0.205	4.2
73078	5	—	—	0.013	0.025	0 091	0.181	4.5
73079	20	—	—	0.030	0.031	0.140	0.147	4.6
Sebangau area								
73182	10	11.48	0.442	0.027	0.010	0.013	0.057	4.3
73183	25	—	—	0.009	0.023	0.048	0.078	4.4
Kelingan area								
73144	20	4.67	0.140	0.007	0.021	0.047	0.228	4.3
Mentaja area								
73085	40	11.00	0.205	0.013	0.021	0.055	0.098	—
73087	40	—	—	0.033	0.020	0.027	0.067	3.8
73091	15	12.59	0.464	0,095	0.019	0.007	0.040	4.2
73092	35	—	—	0.006	0.019	0.015	0.090	4.0
73098	10	21.69	0.669	0.032	0.025	0.028	0.037	4.3
73099	40	—	—	0.013	0.016	0.033	0.057	4.3

For the cultivation of swamp rice, which requires abundant quantities of water, these soils are decidedly unsuitable. In the areas where the Bandjarese method of swamp rice cultivation is practised or is being introduced (along the S. Barito and S. Murung) the river levees are not utilized for this purpose. The only form of rice grow-


SILT 50-5 μ
GRANULAR COMPOSITION
of
• RIVERAIN SOILS
• SAND CONTAINING PEMATANG SOILS
SAND
> 50 μ
CLAY
< 5 μ


SILT 50-5 μ
• SWAMP SOILS
(• ORGANIC SURFACE LAYER)
SAND
> 50 μ
CLAY
< 5 μ


SILT 50-5 μ
• ACID CLAY IN SUBSOIL
SAND
> 50 μ
CLAY
< 5 μ

ing, practised more especially on the levees along the western rivers, is the "huma" or shifting cultivation (rice varieties with a growing period of 7-8 months) which is dependent on rainfall. As a rule the fields are abandoned after a few years; the reason reported being the fact that the yields fall off considerably after prolonged occupation. Apart from weed growth and the occurrence of mice plagues, the originally humus-containing soil is exhausted and the crops have to depend on the physically unfavourable and chemically poor mineral substratum.

The favourable hydrological conditions have induced the local population to utilize the gently sloping levees along the rivers for the cultivation of commercial crops, such as rubber and rattan which do not make heavy demands upon the soil. Coconuts are also successfully cultivated near the settlements on these soils.

b. The swamp soils which take up by far the greater part of the tidal region have, as has already been stated and may also be seen from the texture diagrams on page 18, about the same granular composition as the river levee soils. They differ from the latter in having a higher organic matter content in the upper layer (shown in the diagram by a higher content of pseudo-sand particles which in reality are clay particles granulated by organic matter) and, finally, by the usually homogeneous grey colour of the mineral subsoil. The swamp soil again contains only a slight percentage of sand.

The properties of the swamp soils depend to a great extent on the quantity of organic matter they contain. Under natural vegetation of swamp or peat forest, the swamp clay is covered with a more or less pure layer of peaty material which will be discussed in more detail in the next chapter. In the swamp areas which for some years are reclaimed for paddy fields, the content of organic matter has gradually decreased as a result of tillage and supply of fresh water; it amounts to about 10-30 per cent. The fact that the organic matter does not only decrease quantitatively but is, moreover, decomposed in a more readily available form, is apparent from the comparison of the organic matter figures in Table 4 obtained according to the methods of DENNSTEDT and ISCHTSCHERIKOW. The latter gives the percentage of readily oxidizable organic matter.

These figures show that, as the percentage of organic matter decreases, the average percentage of readily oxidizable matter increases. The C/N ratio decreases from roughly 25-50 in the original state to 15-20 in the cultivated soil.

TABLE 4. COMPARISON BETWEEN PERCENTAGE OF TOTAL AND READILY OXIDIZABLE ORGANIC MATTER.

Number of samples	Per cent. organic matter according to Dennstedt	Percentage readily oxidizable organic matter
7	0 — 5	74
11	5 — 10	55
11	10 — 15	48
5	15 — 20	54
7	20 — 30	46
4	30 — 60	33
3	60 — 100	28

The swampy subsoil sticks to the tools in the same way as does the river levee soil. When dry it becomes as hard as stone and is practically untillable. Although the permeability of the purely inorganic soil leaves much to be desired, the water movement in the cultivated soils is still fairly favourable because of the presence of root cavities and channels originating from the earlier forest vegetation.

For the Bandjarese swamp rice cultivation this soil structure is beneficial rather than detrimental. The method of tilling applied here consists in superficial treatment with a "tajak", a scythe-like implement with a short handle (Fig. 6). Tillage is consequently restricted to the humous top layer of the soil. The water requirement of the paddy field on the one hand is limited because of the poor permeability of the subsoil, on the other hand the necessary water movement in the soil continues due to the presence of the root channels mentioned.

The chemical composition of the swamp soils is also closely related to the percentage of organic matter (cf. Table 5). The very humous upper layers are rich in nitrogen (average 0.5% N) and often have a very high content of phosphate soluble in 25 per cent. hydrochloric acid. Thus some swamp paddy fields near the Serapat canal were found to contain 0.153-0.248 per cent. P_2O_5 in the top soil. The potash content also shows a distinct correlation with the organic matter content. Even if it is borne in mind that only about 50 per

TABLE 5. CHEMICAL COMPOSITION OF SOME CULTIVATED SWAMP SOILS.

Soil sample No.	Depth of sampling cm	Organic matter (Dennstedt) %	N (Kjeldahl) %	Soluble in 25 per cent. HCl				pH
				P_2O_5 %	K_2O %	CaO %	MgO %	
erapal area								
72936	5	33.95	—	0.270	—	—	—	4.5
72937	15	56.29	1.344	0.223	0.184	0.060	0.147	3.8
72938	35	7.87	—	0.013	0.033	0.040	0.165	3.5
72939	5	11.21	0.425	0.153	0.069	0.035	0.099	4.3
72940	20	6.32	0.156	0.013	0.031	0.034	0.153	4.1
72941	35	8.17	0.179	0.018	0.032	0.050	0.199	4.1
72944	5	15.94	0.345	0.191	0.036	0.050	0.088	4.4
72945	15	15.27	0.381	0.220	0.039	0.054	0.101	4.4
72946	40	12.51	0.315	0.115	0.036	0.042	0.122	3.9
72947	3	21.20	0.680	0.284	0.061	0.126	0.119	4.5
72948	7	—	—	0.100	0.053	0.080	0.150	4.2
lalak area								
73028	5	12.58	0.187	0.009	0.041	0.081	0.397	4.0
73029	50	12.60	0.564	0.039	0.035	0.040	0.071	4.0
73036	30	10.66	0.194	0.050	0.041	0.082	0.187	4.4
73063	5	17.63	0.757	0.188	0.032	0.027	0.060	4.4
elajan area								
73007	5	22.87	1.038	0.369	0.082	0.099	0.194	5.0
73008	15	5.22	0.182	0.013	0.024	0.060	0.270	4.8
73009	35	1.91	0.086	0.008	0.024	0.075	0.380	4.6
73013	10	22.91	0.795	0.088	0.056	0.259	0.334	5.3
73014	25	6.55	0.204	0.006	0.028	0.148	0.373	5.1
erusan area								
72958	8	8.79	0.380	0.012	0.020	0.087	0.130	4.5
72961	10	10.52	0.414	0.012	0.033	0.102	0.108	4.4
72968	10	17.84	0.682	0.044	0.036	0.054	0.135	4.4
72969	30	3.49	0.127	0.012	0.031	0.052	0.162	4.2
73195	7	18.41	0.592	0.074	0.056	0.125	0.224	4.9
73196	30	—	—	0.015	0.027	0.061	0.227	4.7
73197	8	23.81	0.903	0.083	0.044	0.173	0.244	4.9
73198	30	—	—	0.014	0.031	0.104	0.243	5.1

Table 5 continued.

73205	8	26.50	0.754	0.054	0.040	0.158	0.236	4.7
73206	20	—	—	0.017	0.028	0.081	0.224	4.8
73 08	20	—	—	0.023	0.038	0.119	0.317	4.9
Klampan area								
72961	10	29.87	—	—	—	—	—	4.6
72965	25	3.36	0.133	0.012	0.025	0.030	0.062	4.3
72974	25	6.11	0.132	0.014	0.020	0.028	0.057	4.0
Sebangau area								
73182	10	11.48	0.442	0.027	0.010	0.013	0.057	4.3
73183	25	—	—	0.009	0.023	0.048	0.078	4.4
Ketingan area								
73149	25	—	—	0.006	0.021	0.029	0.066	4.1
73168	15	12.28	0.359	0.019	0.020	0.057	0.034	4.4
73169	40	—	—	0.009	0.014	0.033	0.049	4.3
Mentaja area								
73114	8	13.50	0.479	0.121	0.024	0.035	0.062	4.5
73115	25	—	—	0.006	0.017	0.021	0.070	4.4
73128	20	—	—	0.017	0.053	0.077	0.273	4.7

cent. of these plant nutrients in the organic matter is present in readily available form, the figures in Table 5 show that the fertility of the swamp soil is derived entirely from its humous top layer. The mineral subsoil is usually deficient in phosphorus (particularly so in the western swamps) and the percentage of potassium is also lower.

Top layer and subsoil are both deficient in calcium and usually also poor in magnesium. Consequently the soil reaction is always strongly acid (pH 3.5-5.0). The unsaturated character of the organic matter and the clay is substantially influenced by certain acid substances in the subsoil, brought to the surface by the ground-water. The presence and significance of this acid clay, mainly occurring in the subsoil of the eastern tidal region, will be discussed in more detail in another chapter.

The swamp soils inundated by brackish water during a certain period of the year are characterized by a relatively higher lime and magnesia content, and by a pH of approximately 5.0 [1]).

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1) cf. Table 5, samples Nos. 73013/14 in the Kelajan area, Nos. 73195/96, 73197/98, 73205/06 and 73028 in the Terusan area, and No. 73128 in the Mentaja area.

Organic sediments. — Based on the climatic conditions in the tropics, the Institute for Soil Research at Bogor only applies the term "peat" to those organic deposits which in drained condition have a thickness of at least one metre and a minimum content of 65 per cent. organic matter.

Such organic sediments are widely distributed in the peat and swamp forest regions of the Mentaja, Ketingan, Sebangau and Kahajan rivers. In the tidal area east of the S. Kapuas, where a slight water movement still occurs, the layers of pure peat are consequently thinner. They are most common in the centre of the North and South Serapat area, where their presence almost coincides with the occurrence of the primeval swamp forest (compare sample map with vegetation map).

In its pure form the peat consists of reddish brown loose organic material, composed of partly decayed leaves, wood and roots, soaked in a pulpy organic substance. Botanical investigations of the peat substance, carried out by Dr B. POLAK, showed that the samples collected may be divided into two types, *viz.*

A. Forest peat, built up mainly from remains of the earlier or existing swamp forest, mixed with some *Cyperaceae* and fern debris from the undergrowth, and

B. Predominantly grass- and fern peat, mixed with some wood remains, mainly found on the "renah" strips behind the river levees. This usually shallow peat is characterized microscopically by the presence of *Diatomeae* and water-*Crustaceae*, pointing to former inundations. The top layer is sometimes found to contain many galam remains and some charcoal. Pure galam peat, however, has not been found. The conclusion may thus be drawn that this fire-resistant vegetation is of fairly recent date.

In a few cases the grass- and fern peat was found to be overlain by forest peat.

The peat has an enormous water-holding capacity. When the rainy season sets in, large quantities of rain water are absorbed, and seepage only occurs after the organic mass has become saturated. This characteristic property of the peat, which is related to the colloidal composition of the organic substance, is lost for ever in cases of severe drying-up (irreversible dehydration of the colloids).

Being permanently saturated with water, the uncultivated peat is always poor in oxygen. Numerous field analyses have shown that the peat-water flowing off in the eastern tidal region has an acidity ranging from pH 4.2-4.5. In the western areas, however, higher acidities have often been measured (pH 3.0-4.0). The chemical composition of several forest and grass-fern peat samples is shown in Table 6.

TABLE 6. CHEMICAL COMPOSITION OF SOME PEAT SAMPLES.

Soil sample No.	Thickness of peat layer cm	Depth of sampling cm	Organic matter (Denn-stedt) %	In per cent. of dry matter					In per cent. of ash
				N %	ash %	P_2O_5 %	K_2O %	CaO %	SiO_2 %
A. Swamp-forest type of peat with Cyperaceae-fern undergrowth.									
83527	>120	20	82.39	5.26	15.97	0.247	0.136	0.104	63.94
83528	>125	20	74.83	3.67	15.69	0.195	0.138	0.087	66.61
83557	200	50	88.45	6.85	10.41	0.168	0.100	0.250	74.43
83558	150	100	79.43	4.54	23.19	0.148	0.228	0.181	69.55
83600	150	50	91.70	5.65	5.86	0.133	0.096	0.136	64.99
83612	30	15	83.48	5.10	12.56	0.157	0.110	0.068	70.09
83616	60	40	89.06	3.29	8.07	0.123	0.077	0.222	64.04
83618	120	65	94.49	4.84	5.68	0.099	0.064	0.195	57.56
83704	30	20	78.26	2.91	15.26	0.176	0.186	0.238	65.28
83722	30	15	82.49	3.30	15.50	0.234	0.115	0.123	69.18
83725	75	40	84.24	2.59	13.70	0.138	0.154	0.066	67.22
95957	50	25	72.21	1.59	7.32	0.143	0.116	0.193	—
96079	55	35	83.15	1.80	9.67	0.261	0.103	0.160	—
96346	>100	20	80.11	1.95	15.36	0.240	0.129	0.256	—
B. Predominantly Cyperaceae-fern type of peat.									
83488	130	50	82.69	3.03	16.37	0.219	0.152	0.388	61.36
83559	100	200	47.89	1.67	47.90	0.059	0.557	0.124	68.89
83673	80	40	85.09	4.73	15.20	0.280	0.106	0.343	76.86
83694	45	20	90.93	3.67	8.68	0.136	0.035	0.121	63.81
83967	30	15	86.53	2.63	12.69	0.237	0.154	0.183	62.39
83970	60	30	78.09	2.85	17.85	0.192	0.189	0.320	65.94
96037	25	15	55.50	1.63	42.24	0.493	0.395	0.204	—
96144	110	20	87.76	1.69	11.57	0.195	0.092	0.324	—

Although the conditions under which these types of peat have been formed differ widely from those of the European peats, an idea of the figures given in Table 6 can be formed by comparing them with those given by FLEISCHER as an average for European low- and high-moor peat (BERSCH, 1912). The ash content of the Borneo samples is rather high and corresponds more or less with that of European low-moor peat, the average ash content of which is 10 per cent. Approximately 65 per cent. of the ash consists of silica; this high SiO_2 content of tropical forest peat has already been mentioned by WHITE (1924).

As regards the content of plant nutrients the composition of the peat is fairly similar to that of the swamp soil, in which the vegetation is, to some extent at least, still rooted. Like the underlying soil, all peat samples are very poor in lime (average 0.15% CaO calculated on dry matter); the lime content is even lower than that of European oligotrophic high-moor peat, which is roughly 0.35 per cent. The phosphorus content corresponds more closely to that of mesotrophic transition peat. The nitrogen and potash content, however, is decidedly high and usually equals the mean values given by FLEISCHER for eutrophic low-moor peat (*viz.* 2.5% N and 0.10% K_2O respectively, calculated on dry matter). The more the peat is mixed with clay, the higher the potash content.

Although the plant nutrient content of the peat under discussion in therefore rather favourable and this peat might be termed "mesotrophic", it should be borne in mind that only a small part of these nutrients are present in readily available form. If, moreover, we consider its high acidity and its oxygen deficiency, the nutrient value of the peat under natural conditions can be said to be decidedly poor.

By the process of burning the peat — a measure generally practised by the population — its acidity is lowered and the mineral substances become readily available to the crops. These mineral nutrients are, however, rapidly exhausted since they are washed out by the abundant quantities of acid peat-water during the rainy season. The burning must therefore be repeated regularly, until finally all the organic matter has been destroyed and only the physically bad and chemically poor clay soil is left. This method is applied by the inhabitants of the western tidal region, who are not acquainted with the Bandjarese method of cultivation.

In order to safeguard the nutrients accumulated in the peat, attempts will have to be made to effectuate a gradual humification and mineralization of the organic matter without resorting to burning. Agricultural measures should therefore primarily be aimed at the discharging of the acid surface water and the supply of fresh water, while the ground-water table should be gradually lowered. In other words, the primary objective should be controlled drainage.

The process of shrinking and humification of the organic matter, which in temperate zones takes some 20 years for a peat layer of about 3 metres, in the tropics is completed within a few years when there is adequate aeration. Here a shrinkage of 0.5 m per year is not unusual.

In the course of the humification process the macroscopically visible plant residues disappear, the resulting, mainly colloidal, humus being absorbed by the underlying clay. In this way a humous surface layer, about 30 cm thick, is formed, as was frequently observed on the older swamp paddy fields on either side of the Serapat canal. This top soil possesses highly favourable physical and chemical properties, as already stated in the preceding chapter. It is easily tillable, whether wet or dry, and has an adequate moisture-holding capacity.

The peat formations developed from secondary vegetations differ greatly in their agricultural qualities. Three factors play an important part in this respect:

1. A large amount of galam debris is considered unfavourable, as the galam detritus has been found to be strongly acid and to contain sulphates.

2. Recurring fires may have highly adverse effects; on the one hand, they give rise to pure galam vegetations (No. 6 on the vegetation map), on the other hand, the underlying mineral soil is hardened by the fires to such a degree that its permeability to water and plant roots decreases markedly. Especially in the Terusan and Klampan area the fires have had this disastrous effect. As a rule the "physiologically dry" layers of ash are here quite thick and constitute a highly unfavourable cultivation medium for rice. These conditions are impaired by the underlying hardened clay which is impervious to rice roots.

3. The possibility of fresh water supply is also a very important factor. When the supply is insufficient it is highly probable that noxious substances will accumulate in the organic layer.

The best organogenic sediments are generally found under the secondary vegetations, referred to as Nos. 5, 7 and 9 on the vegetation map. Thick organic formations under No. 9 consist of forest peat, on which, after clearing, a more or less thick layer of grass- and fern peat has developed; thin formations resemble more closely the peat deposits under vegetation type Nos. 5 and 7.

In the brackish-water zone the organic matter under nipah (Nos. 10 and 11) as well as in the reed-*Cyperaceae* plains (No. 12) is mainly restricted to a thin dark-coloured humus formation at the surface. Its agricultural value is not significant, due to the high chlorine content of the ground-water.

Acid clay in subsoil. — As already stated on page 22, a bluish-grey, very acid clay is found at an average depth of one metre in the swamp soil of the eastern tidal region. As regards granular composition, this acid clay does not differ from the overlying river clay. Physically it is a heavy, plastic and impermeable soil. It contains 15-30 per cent. organic matter. The chemical composition is given in Table 7.

TABLE 7. CHEMICAL COMPOSITION OF SOME ACID CLAY SUBSOIL SAMPLES.

Sample No.	Depth of sampling cm	Organic matter (Dennstedt) %	Soluble in 25 per cent. HCl				Soluble in water		pH
			P_2O_5 %	K_2O %	CaO %	MgO %	SO_3 %	Cl %	
83672	100	19.99	0.011	0.023	0.046	0.216	2.795	0.117	2.4
83678	140	16.55	0.051	0.042	0.067	0.371	3.376	0.024	2.8
83684	120	20.68	0.014	0.032	0.096	0.520	4.125	0.041	2.5
83687	120	17.25	0.100	0.038	0.088	0.502	1.378	0.042	3.2
83733	120	28.25	0.033	0.053	0.162	0.464	6.840	0.088	2.3
83742	90	26.66	0.013	0.038	0.148	0.427	3.440	0.127	2.4
83966	120	25.38	0.023	0.043	0.193	0.485	2.068	0.135	2.5

The content of phosphoric acid, potash and lime is of about the same order as that in the overlying river clay. The percentage of magnesia, however, is much higher than that of lime, pointing to marine influences.

Moreover, this clay contains a remarkably high percentage of water-soluble sulphate (varying in the samples investigated from 1.38-6.84% SO_3) and shows a very strongly acid reaction (pH 1.7-3.2).

These phenomena indicate that the soil was deposited in sulphate-containing brackish water or has been soaked in this water. This clay should therefore be regarded as the surface layer of the marine Barito Basin which during the Pleistocene has been completely exposed to brackish-water influences and must at that time have been a true tidal marsh (cf. page 7). The organic matter content of this clay results from the halophytic vegetation of that period and from various organisms living in the water and in the mud.

If, as in the case under discussion, such a sulphate-containing soil is sealed off by a more recent layer of river clay, certain processes take place. These processes have been described, among others, by VAN DER SPEK (1950). In a recent publication he explains the origin of the acid clay as follows:

When there is no free oxygen but easily decomposable organic compounds are present, a reduction of the calcium sulphate washed in by sea water is brought about by bacterial action, according to the general formula:

$$CaSO_4 + 8\ H \rightarrow CaS + 4\ H_2O$$

Under influence of water and carbonic acid liberated by the decomposition of organic matter, hydrogen sulphide and calcium carbonate are formed, according to the reaction equation:

$$CaS + H_2O + CO_2 \rightarrow CaCO_3 + H_2S$$

The hydrogen sulphide acts immediately on the iron compounds present in the soil, so that ferro sulphide and elemental sulphur are formed:

$$Fe_2O_3 + H_2S \rightarrow 2\ FeS + S + 3\ H_2O$$

The FeS-S mixture is then very readily converted into iron bisulphide or pyrite, according to:

$$FeS + S \rightarrow FeS_2$$

The large quantities of carbonic acid formed during the decomposition of organic matter effect a dissolution and leaching of the calcium carbonate in the marine clay.

If this type of soil, in which FeS_2 has been formed under anaerobic conditions, is exposed to the air after drainage, the oxygen from the air will oxidize the sulphides. Finally, the FeS_2 is almost entirely converted into ferro sulphate and sulphuric acid, according to the reaction equation:

$$7\ FeS_2 + 7\ O_2 + H_2O \rightarrow 2\ FeSO_4 + 2\ H_2SO_4$$

If this oxidation occurs in a soil which is poor in lime (as is the case in the South Borneo sediments under discussion), the sulphuric acid formed is not neutralized but further oxidation to ferri sulphate takes place:

$$2\ FeSO_4 + 2\ H_2SO_4 + O \rightarrow Fe_2(SO_4)_3 + H_2SO_4 + H_2O$$

Ferri sulphate is a whitish yellow, solid substance which slowly dissolves in water. By hydrolysis it forms basic ferri sulphate and sulphuric acid, according to one of the following reactions:

$$Fe_2(SO_4)_3 + 4\ H_2O \rightarrow Fe_2(SO_4)_2(OH)_2 + H_2SO_4 + 2\ H_2O$$
$$Fe_2(SO_4)_2(OH)_2 + 2\ H_2O \rightarrow Fe_2(SO_4)(OH)_4 + H_2SO_4$$

As sulphuric acid disappears, owing to leaching or to some other cause, the hydrolysis proceeds. The sulphuric acid formed may cause a highly acid reaction of the soil. Furthermore, it may act on the base-deficient clay, so that aluminium sulphate and, by hydrolysis of the latter, aluminium hydroxide may be formed.

In the sea-clay areas in the Netherlands this light yellow, strongly acid clay, which has the consistency of yellow soap, is known locally as "cat's clay". When it occurs just below the arable soil it is noted for its inferior properties and pronounced infertility.

Recapitulating, it may therefore be said that in the eastern tidal region a type of clay is found in the subsoil, which is rich in iron sulphides, formed by the action of severely anaerobic sulphate-reducing bacteria. In the lime-deficient soil these iron sulphides are oxidized to ferri sulphate which by hydrolysis produces basic ferri sulphate and free sulphuric acid. The acid clay thus formed is extremely injurious, not only because of its high acidity but also because of the high content of toxic basic ferri sulphate and possibly aluminium sulphate.

The presence of such FeS_2-rich subsoils is also known elsewhere in Indonesia. WHITE (1922) reports that on the experiment rice farm in the Selat Djaran "polder" near Palembang a subsoil rich in sulphur compounds (5-7 per cent. SO_3) had been ploughed up into the arable top layer. Due to the insufficient supply of fresh water the basic ferri sulphate, formed by oxidation, could not be washed out and the rice crop failed completely.

VAN DIJK (1937) described similar conditions in the Alabio polder in Hulu Sungei (S. E. Borneo).

In the subsoil samples of the eastern tidal region of South Borneo the content of water-soluble sulphates (determined as SO_3) ranged from 1.38 to 6.84 per cent. The percentage of active iron and aluminium determined in a few samples of this acid clay and the overlying river clay are shown in the following table.

TABLE 8. PERCENTAGES OF READILY SOLUBLE IRON AND ALUMINIUM IN RIVER CLAY AND MARINE CLAY.

Soil type and sample No.	Soluble in 0.5 N acetic acid in mg per g soil		pH (H_2O)
	Fe_2O_3	Al_2O_3	
River clay			
No. 95987	0.181	0.358	3.9
No. 96205	0.117	0.567	4.6
Acid subsoil clay			
No. 96132	4.298	3.119	3.0
No. 96136	5.379	2.168	2.8
No. 96146	3.300	2.115	2.7

These figures show that the acid clay can contain very high percentages of readily soluble iron and aluminium compounds. Owing to the extremely high acidity of the soil these compounds will be optimally soluble and will have a highly toxic effect on the crops.

It should be pointed out once more that the marine clay in reduced condition does not necessarily have to be particularly acid. In the non-reclaimed areas under permanently anaerobic conditions, the extremely high acidities mentioned have only rarely been measured in the field. Acidification only sets in when the reclaimed land is excessively drained and the sulphides in the subsoil are oxidized. The highly poisonous and insoluble basic ferri sulphate formed is then often found in the form of a greenish yellow efflorescence on the clay dug up from the drainage ditches, as a rule together with dirty white feather alum efflorescences [1]).

In digging drainage canals, or "andils", the population often builds small dikes, or "tembokans" from this acid soil, on which they plant secondary crops. This cannot be done, however, until the poisonous compounds have been sufficiently washed out by rain water. It was repeatedly observed that rice plants coming into contact with water washed from the dikes, were poisoned.

It is evident that the acid clay in the subsoil will constitute a permanent danger to the crops. Dissolved salts from this clay can at all times enter the arable layer, and there are numerous examples in these areas of crops failing as a result of contact with the poisonous ground-water. This phenomenon was most noticeable along the Klampan canal, where the rubber trees which had come into contact with the mud dug from the canal, had died off.

III. Properties of the water

Ground-water in reclaimed areas. — For swamp rice cultivation, the obvious agricultural method in the eastern tidal region with its high ground-water table and noxious substances in the subsoil, it is imperative to investigate the properties of the ground-water with which the root system will come into contact. In field survey work qualitative analyses of the ground-water have therefore been carried out regularly and a number of samples were taken to the laboratory for quantitative analyses. Thus valuable data were collected concerning the nature of the subsoil, and was it possible to draw far-reaching conclusions regarding the agricultural aspect of the "rapak" problem.

It was found that the ground-water in soils which, as a result of drainage, had been exposed to the air for some time, was always strongly acid. Further, the content of iron and aluminium sulphate

[1]) In this connection it may be stated that the native population collects this alum and uses it for the coagulation of rubber latex.

TABLE 9. COMPOSITION OF SOME GROUND-WATER SAMPLES IN RECLAIMED LANDS.

Origin of water sample	Acidity pH	Evap. residue mg/l	Ignited residue mg/l	In per cent. of ignited residue					
				CaO %	MgO %	Fe_2O_3 %	Al_2O_3 %	SO_3 %	Cl %
Klampan area									
Muddy water from well in galam-forest clearing, 1 1/2 km W. of S. Kapuas.	2.9	1629.2	836.0	7.9	—	3.2	11.4	20.2	2.1
North Serapat area									
Clear ground-water in pit No. 96259/60 in recently reclaimed galam forest, 4 1/2 km from Kp. Telok Tamba.	3.1	338.0	277.0	11.7	—	1.1	0.1	47.5	9.6
Muddy ground-water in pit No. 83645/46, poor paddy field along Andil Membulau.	3.2	733.6	599.2	1.6	2.2	6.6	7.3	46.0	2.2
Muddy ground-water from well along Andil Seluang.	3.9	1760.0	1465.6	2.6	10.7	12.6	0.8	42.6	11.2
Muddy ground-water in pit No. 83651/52 in 2-year old paddy field, reclaimed from dense galam forest.	4.5	432.8	352.0	6.2	5.5	19.1	3.4	48.5	1.6
Brown ground-water in pit No. 83685/87 in 8-year old paddy field, formerly rubber plantation (fired).	5.3	390.4	286.8	7.0	8.6	10.1	3.6	32.0	15.1
Kahajan area									
Muddy ground-water in pit No. 83565/66, clearing in very dense young galam forest, 4 km from river.	4.8	476.4	364.4	2.1	6.4	35.1	0	73.5	1.5
Terusan area									
Brownish yellow ground-water in pit No. 83583/84 in abandoned reclaimed land, 2 km from Bahaur.	5.6	168.4	112.0	5.5	4.9	2.8	3.9	4.3	15.1
South Serapat area									
Brownish yellow ground-water in pit No. 83731/33 in fairly good paddy field, reclaimed from galam-prupuk vegetation, 4 km from S. Barito.	5.8	727.2	602.4	3.8	6.0	5.0	0.4	0.3	26.6

of this water was invariably higher than that of the surface water on non-drained land. The latter always contained only a certain percentage of sulphides.

Even low percentages of soluble ferri and aluminium sulphate in the ground-water have a toxic effect on crops. VILLA (1928) determined a maximum tolerance of aluminium sulphate amounting to 0.00025 g/mol. per litre, i.e. about 87 mg/l, for rice grown in a culture solution. MYAKE (1916) even observed a poisonous effect at the rate of 14 mg Al_2O_3 per litre water. Injurious contents of this order are frequently found in the ground-water in reclaimed areas, as shown in Table 9, giving the results of a number of water analyses. VAN DER ELST (1926) demonstrated that even a concentration of 0.01 per cent. ferro sulphate gives rise to symptoms of poisoning of rice grown in culture solutions. As the iron in the soils is largely present in the ferrous stage, poisoning caused by dissolved ferro sulphate is also liable to occur.

Table 9 gives the results of the analyses of a few ground-water samples from different places. The lime-deficiency of the swamp clay is reflected in the low lime content of the ground-water. The submarine influence to which the subsoils in particular have been subjected in the past, manifests itself in the relatively higher magnesia content of a few samples. The strongly acid reaction of the water may be attributed to the high content of iron or aluminium sulphate.

The harmful effect of high acidity on the growth of rice roots has been demonstrated, among others, by MITRA and PHUKAN (1929) in experiments with Knop's culture solution. At a pH of 3.9 the growth of the roots of young rice plants was found to be markedly inhibited, whereas at a pH of 3.3 there was hardly any root development and the seedlings died off after a short time. The tolerance of the different rice varieties varies, however. No comparative experiments have been carried out so far with the "padi bajar" varieties. In the field, however, it was observed that the toxic effect started at a pH of about 4.0, whereas the "padi bajar" always showed a favourable development and yielded well in fields where the ground-water had a pH of 5.5-6.0.

Chlorides are always present in the ground-water. It is not possible to establish the concentration at which chlorine begins to have a harmful effect on rice. A number of experiments have shown that many factors are involved, such as the nature of the soil, the time during which the plants are in contact with the salt water, the stage of development and the variety of the rice.

Pot experiments (DENNETT, 1937) have shown that 0.2 per cent. sodium chloride in the irrigation water has no harmful effect on the development and setting of rice plants; 0.3 per cent. NaCl, on the other hand, is markedly injurious. Field and pot experiments in Louisiana (QUEREAU, 1920) have revealed that following a previous prolonged inundation with water containing 0.6 per cent. NaCl, a second inundation with 0.255 per cent. NaCl already had a noxious effect on the rice.

From these experiments we may infer that the chlorine content of the ground-water in the tidal region is usually not such as to have an injurious effect on the crops. As one approaches the brackish-water zone, however, the chlorine content of the ground-water increases. Nevertheless, under present hydrological conditions this content is not injurious up to about 8-10 km from the coast. The fact that the salinity-line shifts towards the coast in the rainy season, and in the reverse direction in the dry season, should, however, be borne in mind. For this reason it is extremely difficult to draw a line on the map up to which rice may be safely grown. In the South Serapat area this line has been drawn between Sungei Banda on the S. Barito and kampoong Lupakantasan on the S. Murung. South of this line the rice often has infertile panicles which phenomenon is attributed to the injurious effect of sodium chloride.

As the South Terusan area was completely inundated at the time of the survey it was not possible to indicate a salinity-line in this area.

Surface water in unreclaimed areas. — This surface water which is mainly supplied by rainfall, usually has a light yellow to brown colour due to its high content of dissolved organic compounds. As the analytical results of a few water samples show in Table 10, the content of organic matter (loss on ignition) constitutes from 37 to 85 per cent. of the total amount of dissolved matter (evaporation residue).

The surface water is consequently poor to very poor in mineral substances (ignited residue), which have been transferred from the subsoil, mainly by diffusion.

As a result of the deficiency in bases of the peaty top layer and the underlying mineral soil, the surface water is also very poor in calcium and magnesium. Its reaction is, as a rule, moderately acid

TABLE 10. COMPOSITION OF SOME SURFACE WATER SAMPLES IN UNRECLAIMED LANDS.

Origin of water sample	Acidity pH	Evap. residue mg/l	Ignited residue mg/l	In per cent. of ignited residue					
				CaO %	MgO %	Fe_2O_3 %	Al_2O_3 %	SO_3 %	Cl %
Terusan area									
Brownish yellow surface water in galam forest, influenced by swamp forest beyond.	5.2	108.8	33.6	5.1	13.1	9.2	—	10.1	36.9
Brown surface water from "andil" near pit No. 83480/81, 300 m from S. Terusan.	5.7	126.4	68.8	2.9	10.3	6.3	1.0	3.1	9.7
Brown surface water in swamp forest with 30 cm thick peat layer, 800 m from S. Terusan.	5.2	120.0	42.4	4.0	1.9	11.8	9.4	3.3	26.5
Brownish yellow surface-water in high galam forest, 1.7 km from S. Murung near S. Poko.	5.1	1476.8	225.6	2.1	5.5	23.0	5.2	37.1	14.9
Same, 2.5 km from S. Murung.	6.0	129.6	58.4	3.4	8.4	18.2	10.1	3.6	28.4
Brownish yellow surface water in land covered with reed, sedges and nipah, 2 km from mouth of S. Kahajan.	5.9	142.4	90.4	6.7	5.8	6.2	10.6	6.1	18.8
Kahajan area									
Brown surface water in young and very dense galam forest, 1.5 km from S. Kahajan near S. Berangas.	5.8	108.8	68.0	5.7	3.9	36.0	21.3	5.0	8.1
Same, 4 km from S. Kahajan.	5.9	149.6	88.0	4.5	4.2	56.6	2.5	1.6	7.5
South Serapat area									
Brownish yellow surface water in devastated swamp forest, 5.5 km from S. Lupak near S. Teras.	5.1	108.8	36.8	5.4	6.8	3.5	31.3	3.8	10.6

(pH 5.0-6.0), and is therefore much more favourable than the high acidity often measured in the subsoil water. The content of iron and aluminium sulphate is generally low. Stagnant water from the extensive galam complexes exposed to recurrent fires (vegetation types No. 4 and 6), shows a noxious reaction, however, and contains many iron and aluminium compounds derived mainly from the thick layers of ash. A reddish brown precipitate on the vegetation, known among the Bandjarese population as "tagar" or rust, and a crystal-clear colour of the water itself are an indication of a fairly high concentration of noxious substances in this surface water.

On the whole, the chlorine content of the surface water is low. Only in the brackish-water zone and along the estuaries where, particularly during the dry season, the land is inundated with saline water at spring tides, has a higher and noxious chlorine content been measured. By planting salt-resistant rice varieties it is possible to restrict this harmful effect.

When the Bandjarese method of swamp rice cultivation is practised, as is done along the Serapat canal and the Barito river, the surface water from the surrounding unreclaimed swamp forests is always used for supplemental irrigation. Only a moistening action can be attributed to this irrigation water. It is too poor in mineral nutrients to have any fertilizing value.

The clear surface water from the extensive, severely burned galam complexes is inferior for irrigation, since this water, as already stated, always contains a high percentage of ferri and aluminium sulphate.

River water. — From an agricultural point of view supplemental irrigation with water from the big rivers is preferable to that with surface water from the swamps. The river water is rich in oxygen and will accordingly have a beneficial effect on the biological and chemical processes in the peaty top layer in which the rice is rooted. Further, the insoluble compounds in the soil will be oxidized to sulphates and washed out easily.

The paddy fields near Marabahan afford a good example of the beneficial effect of the Barito water on the rice. The yields of paddy fields deriving their additional water from the Barito river are on the whole higher than those of the fields along the Serapat canal, where oxygen-deficient swamp water is used.

An idea of the composition of the river water may be obtained from Table 11, giving the analyses of a few samples taken at random during the dry season.

TABLE 11. COMPOSITION OF SOME RIVER WATER SAMPLES.

River	Date of sampling	Silt content mg/l	Acidity pH	Evap. residue mg/l	Ignited residue mg/l	In per cent. of ignited residue			
						CaO %	MgO %	$Fe_2O_3+Al_2O_3$ %	SO_3 %
S. Murung	Sept. 24, '40	11	6.2	48.4	28.0	24.6	6.4	3.5	—
S. Kapuas	Dec. 4, '36	10	—	67.0	21.5	9.3	6.5	11.6	—
S. Kapuas	Aug. 4, '38	—	6.1	54.0	22.0	9.1	—	3.5	0
S. Kahajan	Sept. 25, '38	12	6.7	93.6	46.4	3.2	0	2.6	8.3
S. Kahajan	Oct. 6, '40	—	6.3	62.8	40.0	21.5	0.5	3.0	—
S. Ketingan	Sept. 20, '38	—	4.8	51.2	24.8	4.8	0	17.7	19.4
S. Mentaja	Nov. 24, '36	9	4.0	72.5	34.0	4.7	4.7	10.3	11.8

As may be expected, the silt content of these rivers which have been sampled in their extreme lower courses, is very low (approximately 10 mg per litre). The brown colour of the water is therefore not attributable to the silt content, but to the dissolved organic matter. This is apparent from the high percentages of loss on ignition, especially in the water of the S. Kapuas, S. Mentaja and S. Ketingan. The evaporation residue was found to contain 50-70 per cent. organic matter, as against 35-50 per cent. in the S. Barito (S. Murung) and S. Kahajan.

Although the water from all rivers from which samples were taken is decidedly poor in lime, there is also a slight difference in the lime content, both absolutely and relatively (i.e. in per cent. of the ignited residue) between the S. Murung and the western rivers, the S. Kahajan coming in between. As a result thereof, the water of the eastern rivers is slightly acid and that of the western rivers strongly acid.

If used for irrigation purposes this river water — and this applies to the eastern rivers as well — will have little or no fertilizing value, since it is poor in silt and dissolved mineral matter. Nevertheless the Barito water, for instance, is the most suitable water for the improvement of the biological conditions of the tidal swamp rice fields. The water from the S. Kahajan is also suitable for irrigation. In comparison, the reddish brown, peaty water of the S. Kapuas, upstream of Kuala Kapuas, is of inferior quality.

IV. SWAMP RICE CULTIVATION AND AGRICULTURAL MEASURES

In the tidal region rice field complexes of some importance are only found where soil and water conditions are favourable, i.e. on the "rantjah" strips along the S. Barito and S. Murung, and in the areas on either side of the Serapat canal.

Notwithstanding all attempts made by the Government, no paddy field area of any significance has as yet been developed in the Terusan and Klampan region. Apart from the fact that the local Dyak population is less skilled in cultivating rice on irrigated fields, the less favourable soil and water conditions obstruct successful development of this type of rice cultivation. Along the Klampan canal the system of shifting cultivation on superficially drained fields is thus still practised. Paddy varieties maturing in 5 to 7 months are grown here, and the fields are abandoned after some years of occupation.

The permanent rice cultivation on either side of the Serapat canal is of fairly recent date. This land was cleared and drained by transmigrants from the Hulu Sungei and was used for rubber plantations. In 1928 these poorly maintained plantations were, for the greater part, destroyed by a big peat fire. The low rubber prices in the following years were responsible for the change-over to food crop production. The ruined rubber plantations were converted into paddy fields. The initial results obtained in the cultivation of "paddy bajar" varieties were not encouraging however, as the fields were inadequately drained.

When the hydrological conditions had been appreciably improved by widening and deepening of the Serapat canal in 1933, there was a change for the better. The paddy field area was gradually extended until, in 1938, it covered approximately 4000 hectares (MAKALIWY, 1938).

The first stage in reclamation consists in clearing a forest strip where a narrow drainage ditch is dug, so that the land can be superficially drained. Subsequently the entire forest is felled and then burned at the end of the dry season. This procedure is repeated until most of the wood has been cleared away and at the same time the dried surface of the peat layer has been burned away.

As the clearing proceeds the drainage ditch (andil) is broadened and deepened, depending on the draining required by the surround-

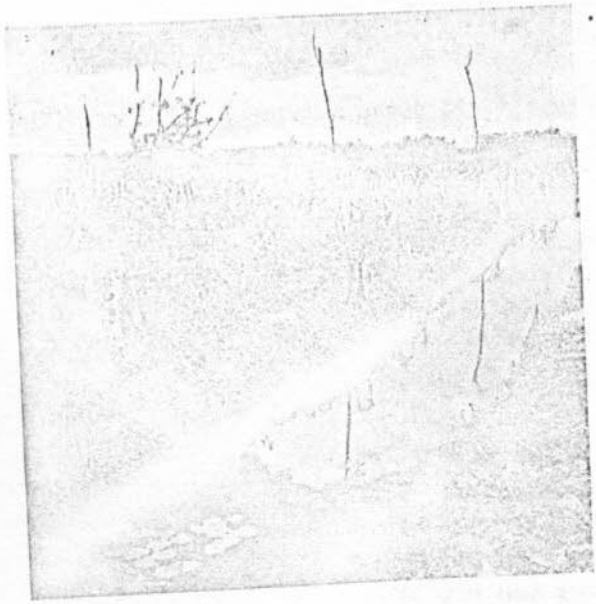

Fig. 5. Clearing in South Serapat area, drained and planted with swamp rice.

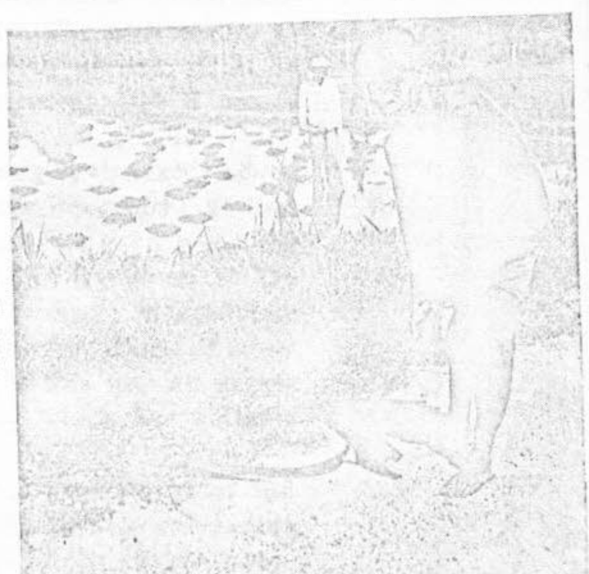

Fig. 6. The "tajak" which the Bandjarese farmers use for clearing swamp weeds. The grass heaps in the background will be spread out after decaying (after KUILMAN and VAN DER MEULEN, 1941).

ing paddy fields. Swamp rice is often planted the same year. In the acid and oxygen-deficient, only slightly decomposed, peat layer, the growing conditions are, however, extremely poor, so that the paddy appears to be diseased and usually produces stalks with empty panicles (Bandjarese: hampa). Only during very dry seasons, as in the 1940 survey, do these one year-old clearings on thick peat layers produce fairly good crops, since growing conditions are then more favourable.

As the drainage ditch reaches its ultimate width and depth, the yields gradually improve. Well-kept andils along the Serapat canal are as a rule 2-3 m wide and are dug 50-75 cm into the mineral soil (Fig. 5). Further south, near Sungei Tamban on the S. Barito for instance, the drainage canals are just as deep but usually wider on account of the higher swamp water level.

As regards the various agricultural measures to be taken for this type of rice cultivation the following points should be observed.

a. The improvement of the hydrological conditions of the paddy fields is of primary importance for healthy root development. The great majority of failures are due to the insufficient care given to drainage. In the first place the noxious dissolved compounds (iron and aluminium sulphates) which have accumulated in the top soil should be removed. The high acidity of the stagnant surface water also has an extremely adverse effect on the water and nutrient supply for the rice roots, since it causes plasmolysis of the hair-root cells.

As already stated, drainage causes considerable shrinking of the organic layers. This shrinkage usually proceeds irregularly, so that the recently cleared lands present an uneven surface. As a result the water level in the field varies considerably and the stand of the crops is accordingly heterogeneous. As the drainage is gradually improved, the organic sediments are increasingly humified and mineralized, and infiltrate into the mineral soil. In this way an arable layer, about 20 cm thick, eventually forms, which has suitable physical and chemical properties.

The influence of the tidal action ensures an adequate water and air movement through the drainage canals, and injurious substances which have penetrated into the arable soil from the ground-water are thus oxidized and washed out in soluble from. Also chlorides are very easily removed in this way.

Other provisions for the improvement of the hydrological conditions concern the protection of the low-lying lands against inundations by saline and brackish water at high tide because there is no counter-pressure of the surface water when the land has been drained. Where necessary, dikes should be made (for which purpose the soil dug up from the canals can be used), whereas self-regulating locks are to be placed in the canals and creeks. An example of such a system of controlled drainage can be found in the Panchang Bedena rice area in Selangor in Malaya (WULFF, 1939).

With such a system of controlled drainage it is also possible fully to utilize the annual rainfall and thus to prevent any shortage of supplemental water from the hinterland.

b. The maintenance of the arable soil also deserves full attention.

The tilling required in Bandjarese rice cultivation consists, as already stated, in a superficial peeling with a "tajak", to cut off and destroy the weeds just below the soil surface. This is quite sufficient to prepare the humous top layer for planting. Deeper tillage is not even justifiable since, firstly, it would bring about too rapid decomposition of the humus reserves and, secondly, the risk of poisonous sulphides and sulphates present in the subsoil being worked into the arable layer.

An exception of this superficial tillage with the "tajak", commonly practised in the tidal region, is the treatment which should be applied on the galam lands where recurrent fires have had an adverse effect. The "physiologically dry" layer of ash and the fire-hardened mineral soil constitute a highly unfavourable cultivation medium and should therefore be mixed as thoroughly as possibly with the underlying clay. It is obvious that on these former galam soils, the humus resources of which have for the greater part been destroyed by the fires, the yields will usually be substantially lower than those attained on the former swamp forest soils.

Tillage with the "tajak" should be regarded as a kind of green manuring. The mown swamp weeds are collected into small heaps (Fig. 6). Later on the decayed heaps are evenly spread out and very superficially worked into the soil with the tajak. In this way substantial quantities of humus are added to the arable soil every year. Since the swamp vegetation has taken up mineral substances from the deeper subsoil and from the water, this green manuring is at the same time instrumental in enriching the arable layer with mineral plant nutrients.

This method of green manuring might be improved by sowing *Leguminoseae* which are specially adapted to the local swamp soil and water conditions. In Malaya *Sesbania aculeata* seems to be particularly effective (JACK, 1923).

The results observed in the oldest swamp rice fields along the S. Barito prove that the long periods during which the land lies fallow after harvesting and the continuous supply of organic and mineral matter by green manure contribute in preventing the arable layer from becoming exhausted. The 30-40 year old paddy fields near Marabahan and Bedandan produce satisfactory and practically uniform crops.

c. Application of inorganic fertilizers is not necessary for some time to come. Nevertheless it is recommended to accelerate the neutralization of the swamp soil by combining the system of controlled drainage with the use of lime, particularly with a view to reducing the period of poor yields during the first years after clearing. Field tests with an application of about 1000 kg $CaCO_3$ per hectare are strongly recommended in the first year.

The lime effects a decrease in acidity to a pH beneficial to the rice (EHRENCRON, 1949) and precipitates the mobile injurious sulphates.

Furthermore, attention should be given to certain symptoms of a disease of the paddy, locally called "penjakit habang", which often occurs in reclaiming thick peat layers. Though it has so far not been proved, this rusty-brown discoloration of the rice plants is identical with the so-called "reclamation disease" which attacks grain crops on acid peat soils in the temperate zones. Maize and cassava, which are planted on a small scale as secondary crops in the tidal region, show these symptoms to a lesser degree, although here too the stand of the crops on thick peat is irregular.

Comprehensive agricultural research both in the Netherlands (HUDIG *et al.*, 1926; MULDER, 1938) and in the United States of America (ALLISON *et al.*, 1927) has shown that this disease is caused by a deficiency of micro-elements, in particular by a deficiency of copper. The remedy against this reclamation disease is therefore the application of relatively small quantities of copper sulphate. Field tests with copper salts on land where the rice is severely attacked by "penjakit habang" will, within a short time, show the significance of this trace element for swamp paddy cultivation in the tidal region of South Borneo.

Though the importance of the micro-elements should not be under-estimated, the first points to which attention should be given are: 1. improvement of hydrological conditions, 2. proper humification of the peat and 3. removal of injurious salts from the arable layer.

d. In the interest of the rice cultivation in the tidal region variety tests should be made. This problem has already been studied at the Institute for Botanical Research and the Institute for Agricultural Research at Bogor (Kuilman and Van der Meulen, 1941).

Although the "padi bajar" varieties which can be transplanted several times are undoubtedly highly satisfactory on the low-lying peaty lands, selection for salinity-resistance is necessary as a preliminary to land reclamation of the southern part of the tidal region which is subject to inundation by brackish water early in the dry season. In this connection attention is directed to the native varieties Kariwaja, Seluang, Mas aju, Pudak tjempaka and Seraup.

The yields of the swamp paddy fields vary considerably. The average yields of the established paddy fields in the Kelajan, Serapat and Marabahan area amount to 2000-2800 kgs of unhusked rice per hectare. In the recently cleared peaty lands the mean yields are considerably lower, *viz.* 1200-1400 kgs per ha. Mice plagues which often occur in scattered occupations sometimes compel the population to abandon the land. On the riverain paddy fields in the more densely populated areas of Sampit and Samuda the average yield is also approximately 1400 kgs unhusked rice per ha.

e. Secondary crops. The practice of growing secondary crops on recently reclaimed peat lands is becoming increasingly common with the Bandjarese population. In addition to the maize and cassava already referred to, we may also mention keladi (*Colocasia*) and semangka (*Citrullus*). With a view to the further development of these areas more attention should be given to these crops than has hitherto been the case.

The small dikes separating the paddy fields (tembokans) are suitable for the cultivation of fruit-trees, pine-apple, sugar-cane and various vegetables.

V. AGRICULTURAL ASPECTS

From the available data on the soil and water conditions of the tidal region examined it may be concluded that particularly in the eastern part of this region there are good prospects for a remunerative swamp rice cultivation. The existing paddy complexes with a total area of 50,000 hectares, can not only be substantially improved but also considerably extended. If the measures referred to above are carried out, an area of approximately 275,000 ha can be made suitable for swamp rice cultivation. Some 80,000 ha of this area are situated in the Kelajan and Alalak region east of the S. Barito.. Only little detailed information is available concerning these areas, a large part of which is already under cultivation. The investigations were mainly carried out in the region between the S. Kahajan and S. Barito where the following areas have been found suitable for swamp rice cultivation:

a. The best perspectives are offered by the area of about 64,000 ha between the Serapat canal and the line Lupakantasan — Sungei Banda in the South Serapat region. That part of the country south of this line is considered less suitable on account of its salinity and the presence of a sandy ridge along the S. Lupak, although here satisfactory results may possibly be obtained with salinity-resistant paddy varieties.

In 1939 a rough drainage plan was drawn up for this South Serapat area, according to which the land was to be drained by means of four main canals discharging into the S. Barito and S. Murung (WEHLBURG, 1939). Near Sungei Tamban the first Javanese settlement was founded and a start was made with the digging, with an excavator, of the Tamban canal, parallel to the Serapat canal. At the outbreak of the war, however, the bucket dredger was needed elsewhere, so that the scheme was never completed.

b. Also in the North Serapat region, conditions favour the cultivation of swamp rice in the area between the Serapat canal and the line connecting Marabahan and Muara Mengkatip (about 98,000 ha). The land north of this line is subject to flooding by the S. Barito and is for the greater part covered with dense galam forests, the soil of which is covered with thick ash layers and contains high concentrations of poisonous salts. For these reasons the best plan should be to use this land as a natural water reservoir for the surrounding area.

c. As regards the Terusan region, it is more difficult to estimate the possibilities for swamp rice cultivation. Judging by its light colour, the mineral soil has been more strongly leached. Hydrological conditions are also less favourable, though these may be improved by digging a new canal between the S. Terusan and the S. Kahajan near Dandang. At the same time it will be necessary to protect this area by a system of dikes so as to check the influence of brackish water. It is estimated that an area of approximately 20,000 ha on either side of the S. Terusan as well as an adjacent strip of about 4000 ha along the S. Murung up to Kuala Kapuas can be made suitable for swamp rice cultivation.

d. Finally, there are possibilities in the Kapuas region, namely on the right bank of the S. Kapuas between Mandomai and Kuala Kapuas, totalling about 9000 ha.

e. The Klampan and Kahajan regions, on the other hand, are considered unsuitable for this type of rice cultivation on the grounds of their unfavourable soil and hydrological conditions. The same applies, generally speaking, to the Sebangau, Ketingan and Mentaja regions in the west, which have not been investigated in detail.

The drainage canals for the reclamation of these areas will, where possible, have to be constructed with mechanical equipment. The smaller secondary canals (andils), however, can be dug by hand. The great difficulty in these large-scale clearing operations is that of deciding beforehand the minimum forest area to be retained to serve as a water reservoir for the supplemental irrigation of the paddy fields. An additional problem is that at this early stage we do not know enough about a possible shifting of the salinity-line towards the interior when there is no further counter-pressure of the surface water against the saline water flowing inland at high tide. As already pointed out, a solution of this problem is to be sought in the construction of a system of controlled drainage which includes diking and the use of locks.

A further consideration is the question whether a sufficient number of farmers acquainted with the cultivation of rice on swamp paddy fields will be available for the carrying out of such extensive reclamation projects. Many of the farmers at present working in this region have their interests in the Hulu Sungei in the North and thus do not form a regular part of the community. The cultivation of swamp paddy fields calls for a high degree of cooperation on the part of all farmers whose fields are situated along one particular drainage canal. Where there is no settled community difficulties are bound to occur.

Apart from swamp rice cultivation, these drained areas offer possibilities for the growing of secondary crops, such as maize, cassava, sweet potatoes, etc. Of the commercial crops rubber has already been grown in well-drained localities in the tidal region for a great number of years. Though the production of these native rubber plantations is relatively low, the profits accruing still make this cultivation attractive. The oil palm also offers good prospects on well-drained and less thick peat layers, as the results obtained near Sampit have shown. Coconut palms, however, usually have yellow crowns, probably a symptom of nutrient deficiency.

Finally, there is a possibility of cultivating djelutung or pantung (*Dyera lowii* Hook. f.) Contrary to an earlier belief, this tree is easy to cultivate on peat (VAN WIJK, 1950), a factor of great importance in view of the many drawbacks in collecting this valuable latex, a forest product which is becoming increasingly scarce.

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Pemetaan rawah-pasang Kalimantan Selatan berhubung dengan kemungkinan pertanian

oleh

Ir C. L. VAN WIJK.

(Singkatan)

Dalam penerbitan ini disatukan hasil penjelidikan tanah jang dilakukan ditahun 1938 - 1941 didaerah rawah-pasang sekitar Bandjarmasin. Tudjuan penjelidikan itu ialah menetapkan apakah tjara bersawah jang dilakukan dan amat menandai daerah itu (sawah bajar) mungkin diperluas untuk keperluan pemindahan rakjat dari Djawa.

Asal. — Daerah itu ialah sebahagian dari dataran alluvial jang didapat sepandjang pantai Selatan Kalimantan. Disebelah Barat dataran itu merupakan sesuatu dataran-hanjutan tenggelam; disebelah Timur ia terbentuk oleh penimbunan muara Barito jang dahulunja teluk geosynclinal. Akibat pembentukan itu ialah bahwa berbagai sungai jang dipandang dari Barat ke Timur bertambah pandjang itu bermuara kelaut dengan estuari jang lebar.

Bentuklapangan. — Ia amat merata. Pematang sungai-sungai sedikit sekali membentuk dan bagian-bagian diantaranja boleh dikatakan berada dalam keadaan rawah terus-menerus.

Keadaan air. — Ia seluruhnja dikuasai oleh perbedaan pemukaan air, jang disebabkan oleh pasang. Akibat pasang itu njata disungai-sungai jang besar hingga beratus-ratus kilometer dari muaranja. Pengaliran air rawah-rawah dalam keadaan tak terganggu oleh karena tenaga pembuangan sungai-sungai jang berliku-liku itu ketjil, buruk sekali. Dengan membuat terusan pengaliran air itu dapat diperbaiki dan tanah itu dikeringkan, seperti umpamanja tampak pada terusan Serapat antara Sungai Barito dan sungai Kapuas dan pada terusan Kalimantan antara sungai Kapuas dan Kahajan.

Iklim. — Dari kedua djenis hudjan jang didapat disini (tabel 1), maka jang disebelah pesisir Timur untuk pertanian lebih baik dari jang disebelah Barat, karena adanja musim kemarau singkat selama mana padi itu dapat masak.

Penumbuhan. — Disebelah Barat didapat hutan-hutan rawang jang luas diatas lapisan rawang jang amat masam dan bermeter-meter tebalnja. Didaerah antara muara sungai Kahajan dan sungai Barito keadaan umumnja lebih baik, jang menjebabkan pemusatan penjelidikan ini padanja. Matjam penumbuhan didaerah itu dalam garis besarnja dipetakan (lihat peta penumbuhan).

Penumbuhan pertama, jaitu hutan rawah dimana didapat lapisan-lapisan organa jang tipis (lihat peta pengambilan tjontoh), hanja utuh dipusatnja dirawah-rawah itu, ditempat lain-lain selalu didapat penumbuhan-kedua jang disebabkan oleh pembakaran berupakan padang rumput dan pimping hingga hutan gelam tertutup jang tua (*Malaleuca leucadencron*). Ditepi pantai beberapa penumbuhan air pajau diketemukan.

Keadaan tanah. — Penjelidikan mineral menjatakan bahwa endapan sungai-sungai disebelah Barat lebih banjak mengandung kwarts tetapi kurang mengandung concresi besi dari pada sungai-sungai disebelah Timur (tabel 2). Dalam besar butirnja sedikit sekali perbedaan antara tanah pematang (tanah rantjah) dan tanah rawah (tanah baru) jang djauh dari sungai itu. Kedua-duanja lempung liat dan berat jang miskin terhadap basa dan amat masam (tabel 3). Jang disebutkan tanah-baru itu dilapisan atasnja mempunjai kadar bahan organa jang lebih tinggi, maka karena itu lebih baik dibekali dengan bahan makanan tanaman daripada tanah-pematang jang miskin terhadap bahan organa itu (tabel 5 dan 6). Pada hal tersebutlah terletak kesuburannja maka dari itu sedalam-dalamnja dibitjarakan kepentingan penghumusan dan pemineralan jang teratur dari bahan organa berupa rawang semulanja, untuk mendapatkan tempat bertanam padi sebaik-baiknja.

Segala tindakan pertanian pada tjara bersawah orang Bandjar ditudjukan pada pengaliran dan pemasukan air rawah masam itu jang teratur. Pengaliran jang terlalu tjepat mengakibatkan penjusutan rawang dan pengoksidaan jang terlalu tjepat dari lapisan atas organa itu. Pembakaran berulang-ulang pun menimbulkan akibat jang berbahaja karena pembentukan lapisan abu jang rapat dan tumbuhnja hutan gelam jang menghasilkan humus jang buruk.

Akibat buruk lain jang timbul oleh pengaliran air jang tjepat ialah bahwa bahan-bahan beratjun masuk ditanah penanaman. Tanah bawah daerah rawah disebelah Timur ialah lempung laut berkadar sulfida jang tinggi (tabel 7). Djika oleh pengeringan lempung itu bersinggungan dengan udara maka sulfida itu dioksidakan. Ditanah jang miskin terhadap kapurnja maka terbentuk sulfat besi, jang oleh penghydrolytan menghasilkan sulfat besi basa dan asam sulfat bebas. Pun dapat pula terbentuk sulfat aluminium. Oleh karena deradjat masam (pH 1.7-3.2) maupun kadar sulfat besi dan aluminium jang tinggi itu, maka lempung itu amat berbahaja (tabel 8).

Bahaja air-tanah jang bersinggungan dengan lempung beratjun itu luas sekali diperbintjangkan (tabel 9). Pada berbagai tempat dari daerah rawah jang dipertanikan, hal tersebut diatas dilihat, terutama didaerah sebelah menjebelah terusan Klampang, dimana diadakan tjara pembukaan jang salah. Tjara bersawah orang Bandjar (sawah bajar) sebaliknja berdasarkan benar sekali atas pembaharuan air jang teratur. Disawah-sawah sepandjang terusan Serapat digunakan air dari hutan rawah dibelakangnja, jang walaupun tak banjak mengandung bahan makanan tanaman, tetapi tak mengandung bahan beratjun (tabel 10). Sebaliknja air djernih mengandung sulfat dari hutan gelam itu buruk sekali untuk pengairan. Air jang sebaik-baiknja untuk pengairan ialah air sungái jang banjak mengandung oksida, terutama dari sungai Barito (tabel 11), tetapi air itu hanja dapat digunakan untuk pengairan sawah-rawah itu djika membuat bendungan dan kintjir air jang mahal sekali.

Tindakan pertanian. — Luas pula dibitjarakan tindakan pertanian jang diperlukan untuk tjara bersawahnja orang Bandjar itu, jaitu:

a. Pembetulan keadaan air daerah itu. Ini merupakan tingkat pertama dari pembukaan. Hasil jang baik sekali didapat dengan tjara pengaliran jang diatur.

b. Pengolahan jang berarti. Untuk itu harus dilakukan tjaranja orang Bandjar, jaitu menguliti tanah itu dengan tadjak. Ini harus dipandang sebagai pemupukan dengan pupuk hidjau.

c. Pentjepatan penghumusan humus hutan jang masam itu. Baik rasanja mengadakan pertjobaan dengan memberikan kapur pada tanah itu, dan selandjutnja ada tanda-tanda kekurangan tembaga (penjakit habang).

d. Penjelidikan djenis padi. Penjelidikan djenis padi-bajar masih dalam tingkat permulaan dan seharusnja dilandjutkan.

e. Penanaman sela. Tanaman lain-lain mungkin berharga untuk daerah pasang tersebut misalnja sebagai tanaman-tembokan.

Kemungkinan pertanian. — Kemungkinan - kemungkinan sebaik-baiknja untuk pembukaan besar-besaran guna pemindahan rakjat didapat didaerah Serapat Selatan jang 64.000 ha luasnja. Ditahun 1940 dibuka Sungai-Tambahan tetapi oleh petjahnja perang pacifik tak dapat dilandjutkan pengaliran airnja.

Daerah Serapat Utarapun, luasnja 98.000 ha memberi kemungkinan untuk sawah-rawah. Daerah Terusan sebagian dipengaruhi oleh air pajau sehingga pembukaannja agak lebih sukar (24.000 ha). Didaerah pasang Kapuas menurut taksiran hanja 4.000 ha jang dapat digunakan untuk sawah-rawah, sedangkan daerah Klampan dan Kahajan karena keadaan tanah dan air jang tidak bagus itu untuk pembukaan djanganlah hendaknja dikerdjakan. Demikian pula dalam garis besar halnja dengan daerah-daerah jang lebih Barat letaknja sepandjang sungai Sebanggau, sungai Ketingan dan sungai Mentaja, dimana tepinja penjelidikan hanja terbatas pada penindjauan belaka.

APPENDIX IX.

(Reprinted from the Sarawak Gazette dated 6th August, 1949)

"Sarawak's Peat Swamps".

By R.W.R. MILLER.

When rotting of plant remains takes place in the soil in the presence of sufficient air and moisture, a material known as humus is formed. The composition of the material is complex and variable and depends on the conditions under which rotting takes place. Humus is in general a most desirable constituent of soils used for agricultural purposes, as it improves their physical condition and is a rich source of plant nutrients. When the rotting takes place under water where little air is present, very different materials known as peats are frequently formed; again, their composition is variable, but in general, as they stand, they are of no great value for agricultural purposes because they are sour and poor in plant nutrients. Peats are distinct from the fen soils of temperate countries such as the fen soils of Cambridgeshire; such fen soils can under proper management be rich productive soils. The whole subject of soil organic matter is a highly complex one and as yet is imperfectly understood; a great deal of research work has been and is being done in various parts of the world on the matter, but many years must elapse before any great advance in our knowledge of the subject is likely.

Whether or not peat soils formed under tropical conditions can be usefully employed for agricultural purposes is a question of considerable importance to Sarawak, for a recent preliminary survey conducted by the Department of Agriculture has suggested that about one eighth of the total area of the country is accounted for by peat swamps. As is well known, most of the flat land of Sarawak is confined to the coastal and deltaic regions, and the survey has further suggested that peat swamps account for nearly two-thirds of this flat land. The peat swamps are common to all divisions. In Sarawak's peat swamps a slightly raised riverbank or levee formation is usual, the width of the levee being generally about half a mile, and rather wider at the tanjongs. Peat may be found on the levee, but does not usually exceed two or three feet in depth. Behind the levee and away from the bank, the level of the clay or silt subsoil falls and the depth of the overlying peat may often exceed twelve feet. Hillocks are sometimes found in the deep swamp, but are usual.

Some of the peat swamps of South-East Asia are excessively acid, the acidity being associated with a high sulphur content, readily detected by evolution of foul-smelling sulphuretted hydrogen when the swamp is stirred; such swamps are generally useless for agricultural purposes; fortunately no large areas of this type have yet been found in Sarawak, most of the swamps so far examined only being moderately acid.

Some of Sarawak's swamps are, of course, subject to flooding with brackish water, and this may severely limit their usefulness for agricultural purposes.

It must be realised that the mere fact that it is difficult to walk about in tropical peat swamps, and that climatic conditions therein are unhealty and not conducive to sustained physical effort, must severaly limit speed of detailed survey and may be a major factor limiting the success of any schemes for their agricultural development. Furthermore, construction of roads and earthworks necessary for drainage and irrigation schemes under such conditions must inevitably be difficult and expensive.

Effective drainage is an essential preliminary to the utilisation of peat swamps for agriculture, and furthermore, if swamp padi is to be cultivated, the drainage must be adequately controlled. For effective drainage there must be sufficient fall between the clay or silt subsoil of the swamp below the peat and the mean level of water in the watercourse into which drainage must take place. Before drainage is attempted, full water-level and flood data for the watercourse must be collected and there must be an adequate survey of levels over the swamp, not only surface levels but subsoil levels as well. On many of Sarawak's peat swamps, by reason of the lack of adequate fall between the subsoil level of the swamps and the mean water level in the watercourse, construction of drains might merely facilitate entry of flood water (possibly brackish) on to the swamp. Construction of gates at the outfall may be feasible in some cases, but it must be realised that they would have to be built into a substantial and expensive bund. Pump-assisted drainage (as used in parts of East Anglia) is probably not feasible or economic in Sarawak at present. When detailed survey shows that drainage is feasible, deep drains should not be opened to start with, otherwise the peat may merely become a powdery, spongy mass that is difficult to wet; the drains should be shallow to start with and gradually deepened as the peat sinks. The sinking that occurs when peat is drained must not be forgotten, as it may increase the risk of flooding to an unacceptable degree; in Sarawak this aspect is further complicated by the possibility that some at least of the swamps may be sinking as a whole at a greater rate than they are being built up by deposits of alluvium.

Sago grows satisfactorily on fairly deep badly-drained peat in Sarawak and is probably the best crop to grow in such places. This does not mean that sago does best under such conditions; it probably merely means that it can cope with the conditions better than other crops.

As is well known, pineapples do well on the drained peats of South-East Asia and can stand a fairly high water table; unfortunately though the fruit, although large, is often watery and of poor quality.

Swamp padi can be grown on peat, but in the present state of technical knowledge a depth of peat of two to three feet is usually regarded as the maximum depth that can be successfully worked for this crop; as experimental work progresses it may be possible to utilise deeper peats. For this crop it is essential to guard against overdrainage of the swamp; indeed, if no irrigation water is available it may be necessary to leave a considerable area of the swamp under jungle to act like a sponge in retaining a supply of water for the crop in dry periods. Although large-scale irrigation of swamp areas by gravity-fed canal does not in general seem feasible in Sarawak, pump irrigation may in some places be economic, and the matter is receiving the attention of the Department of Agriculture. When an area of shallow peat swamp is first opened for swamp padi the first crop may be quite good, but succeeding crops are all too often very disappointing. Practical experience in Sarawak has shown that adequate water control and cultivation can do much to maintain yields at a reasonable level. A good burn after clearing the fallow growth also seems beneficial. Furthermore, experimental work at the Rantau Panjang Padi Station has shown that profitable responses in yield can be obtained to applications of certain fertilisers; some of this work is promising and it is being followed up as a priority matter.

Enough has been said to show that development of Sarawak's peat swamp for agricultural purposes is not a matter to be lightly undertaken, especially in the present state of technical knowledge with regard to such soils. Attempts by Government to develop such swamps without waiting for detailed surveys to be completed would entail unacceptable risk of waste of public funds.

In conclusion, some quotations from an authoritative communication + recently received from the General Agricultural Experimental Station, Buitenzorg, Java, which gives an account of a settlement scheme on a peat swamp in Java, will be of interest. The swamp described in the article would appear similar to the type of peat swamp usually found in Sarawak. An English translation is included in the publication and the following statements are extracts (slightly amended to correct grammatical errors) from this translation:-

> ".....reclamation carried out by volunteers recruited from the people started in 1924 . . . The arable soils thus produced attracted many people . . . Some attempts at water control have been made, but during the wet season floods still cause heavy damage to crops, and during the dry season water shortage is a dominant factor limiting crop production. Losess inflicted by pests and diseases have also been considerable . . . . The Government, however, found itself morally obliged to support the disillusioned

\+ Communication No. 84, April, 1949.