Report F 7

# Further studies on the occurrence of Drought in Sarawak

by

I·C· Baillie

(Forest Soil Surveyor)

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Soil Survey
Research Section

Forest Department
Sarawak

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### Introduction

The geographical range of the evergreen tropical rain forest is sometimes referred to as the 'everwet tropics' (e.g. Cain, 1969) and it is often assumed that water is in ample supply in these areas and that water deficiency imposes no limitations on plant growth (e.g. Richards, 1952).

However, in Malaysia, it has long been held that phenological changes in some plants are 'triggered' by irregular but fairly frequent periods of moisture stress. Thus it seems that the initiation of leaf fall, flowering and fruiting in many species in the Singapore Botanic Gardens require a preceding period of dry weather and, presumably, moisture stress (Koriba, 1958; Holttum, 1968). Similarly the intensity of defoliation during the 'wintering' of rubber may be partly controlled by the severity of the preceding 'dry' season (Wycherley, 1963).

Detailed examinations of the meteorological records have reinforced the conclusion that periods of moisture stress are not just rare catastrophes in Malaya. Using the mean monthly precipitation figures and estimates of the mean evaporation, based on pan readings and regressions on sunshine, Nieuwolt (1965) concluded that negative water balances occur annually in all parts of the peninsula except for the Singapore - South Johore region. Even in Singapore, by tracing the water balance over a continuous 3 year period, he found that there is a period of deficit in most years. However this is of irregular occurrence and is generally not very prolonged, so that it is not apparent when the mean figures are used. Guha (1969) traced the moisture balance for Kuala Lumpur over a period of 5 months and concluded that, for most soils, the soil moisture status is suboptimal for much of the time, and that moisture deficiency is as great a limitation on the production of vegetation as shortage of nutrients.

Rainfall in Sarawak is generally heavier than that in most of West Malaysia and, on a mean basis, precipitation exceeds measured evaporation throughout the year at all stations with evaporation pans. However, as at Singapore, the mean figures or even the figures for individual arbitrary calendar periods (such as a month) can mask periods of possible moisture stress. This was shown by Brunig (1969) who traced the running 30 day rainfall totals for 5 stations over a period of 2 years. He found that there were spells during which the total of the preceding 30 days was less than 100 mm. for several days on end. These periods increased in frequency from about once a year in the relatively non-seasonal interior to about 3 or 4 per year on the coast. At Miri, a coastal station in North Sarawak, there are even days when the running 30 days total falls to 60 mm.

In addition to his findings based on the meteorological records, he examined the morphology of individual plants and the canopies of the main forest types of Sarawak and concluded that many of the features of the kerangas are advantageous for conditions of frequent moisture stress (Brunig, 1971). It has long been recognised that the relative structural and floristic simplicity of the kerangas ('heath') forest is a reflection of poor site conditions (Richards 1936, 1952, 1965), but it was hitherto thought that nutrients were the main deficiency. Dr. Brunig suggests that moisture deficiency may be equally important.

The present study is to examine some meteorological records to see if the moisture stress periods, as revealed by the running 30 days rainfall, are apparent when soil moisture status is traced using the moisture budget principle of Thornthwaite (1948).

Method

The method involves a daily revision of the soil moisture deficit by calculating the daily moisture budget i.e.

$$S_F = S_I + E_T - P \qquad \text{Eqn. 1}$$

where $S_F$ is the final soil moisture deficit
$S_I$ " " initial " " "
$E_T$ " " evapotranspiration
and $P$ " " precipitation.

When it is estimated that the soil has dried out to the permanent wilting point (PWP) evapotranspiration is assumed to cease, so that the budget simplifies to

$$S_F = S_I - P \qquad \text{Eqn. 2}$$

For the Telok Assam calculations daily evapotranspiration ($E_T$) was assumed to be constant at 0.2 inches (5 mm), so that Equation 1 modifies to

$$S_F = S_I + 0.2 - P \qquad \text{Eqn. 3}$$

This was felt to be justified by the very low variability of the monthly totals of Class A pan evaporation in Sarawak (Baillie, 1970). However subsequent examination of the evaporation for 100 random one - and three day periods from three typical stations showed that, on a short term basis, evaporation is highly variable. This is shown in Table 1.

Table 1

Short term variability of evaporation in Sarawak

| | Single days | | Triads | |
|---|---|---|---|---|
| | Mean (inches) | Coefficient of variation (%) | Mean (inches) | Coefficient of variation(%) |
| Kuching | 0.19 | 44 | 0.61 | 32 |
| Miri | 0.20 | 33 | 0.61 | 20 |
| Kapit | 0.18 | 51 | 0.59 | 25 |

In view of this variability, it was felt that the assumption of constant evapotranspiration was unjustified. For the Kuching, Miri and Kapit calculations the evaportanspiration was therefore estimated from the daily Class A pan evaporation figures.

The relationship between open water evaporation and evapotranspiration by forests is complex, depending upon the height and structure of the canopy, and climatic factors such as temperature, saturation deficit and the frequency and intensity of wind (Brunig, 1971). In West Malaysia Guha (1969) assumed that

$$E_T = E_0 \times 0.7$$

where $E_T$ is evapotranspiration

and $E_0$ is open water evaporation

By considering the water balance of a small catchment covered with Hill Dipterocarp Forest in Selangor, Kenworthy (1969) arrived at a factor of 0.89, which agrees closely with Holdridge's estimate of 0.9 - 1.0 for a forest of 7 layers and canopy height of 40-45 metres (Brunig, 1971). For the purpose of this Sarawak study it is assumed that

$$E_T = E_0 \times 0.9$$

for moist soils.

For soils with a deficit of more than 2/3 of the rooting zone available water holding capacity (AWHC) the evapotranspiration rate is assumed to be halved, i.e.

$$E_T = E_0 \times 0.45$$

This allows for the increasing inaccessibility of the remaining available water to the plant roots. It is a gross over-simplification, as the decrease in uptake, if it occurs (Viehmeyer and Hendrickson, 1955), is gradual and varies with the soils' granulometric composition and organic matter content (Salter and Williams, 1965).

For the Kuching, Miri and Kapit calculations, Equation 1 modifies to:

(a) where $S_I < \frac{2AWHC}{3}$, $S_F = S_I + E_0 \times 0.9 - P$ Eqn. 4

(b) where $S_I \geqslant \frac{2AWHC}{3}$ , $S_F = S_I + E_O \times 0.45 - P$ Eqn. 5

and Equation 2 remains unchanged.

Using the respective budget equations, the soil moisture status was traced from day to day. For the Telok Assam calculations, which were done manually, the number of days on which the soil reached permanent wilting point and the length of drought periods were recorded. The Kuching, Miri and Kapit calculations were done on a microcomputer and the results printed out as monthly totals for the number of days the soil reached PWP (severe stress) and the number of days the soil moisture deficit was greater than 2/3 AWHC (mild stress). The printout did not give length of the mild or severe drought periods within each month.

The calculations were repeated for soils of 6 inches (ca 150 mm) and 3 inches (ca 75 mm) rooting zone AWHC's. Using disturbed samples, Ir. Schelhaas of the Royal Tropical Institute, Amsterdam examined the moisture release characteristics of some West Sarawak soils and found that the plant available moisture (i.e. that held in the pF 2.3-4.2 range) accounted for between 11 and 24% of total soil volumes (J.P. Andriesse, pers. comm., 1971). These figures are high for soils of low organic matter contents, and are probably due to the preponderance of very fine sand and silt in the non-clay fractions of most Sarawak soils (Salter & Williams, 1967). If the AWHC is taken as 1/6 of the soil depth, AWHC's of 6 and 3 inches correspond to rooting zones 36 inches (90 cm) and 18 inches (45 cm) deep.

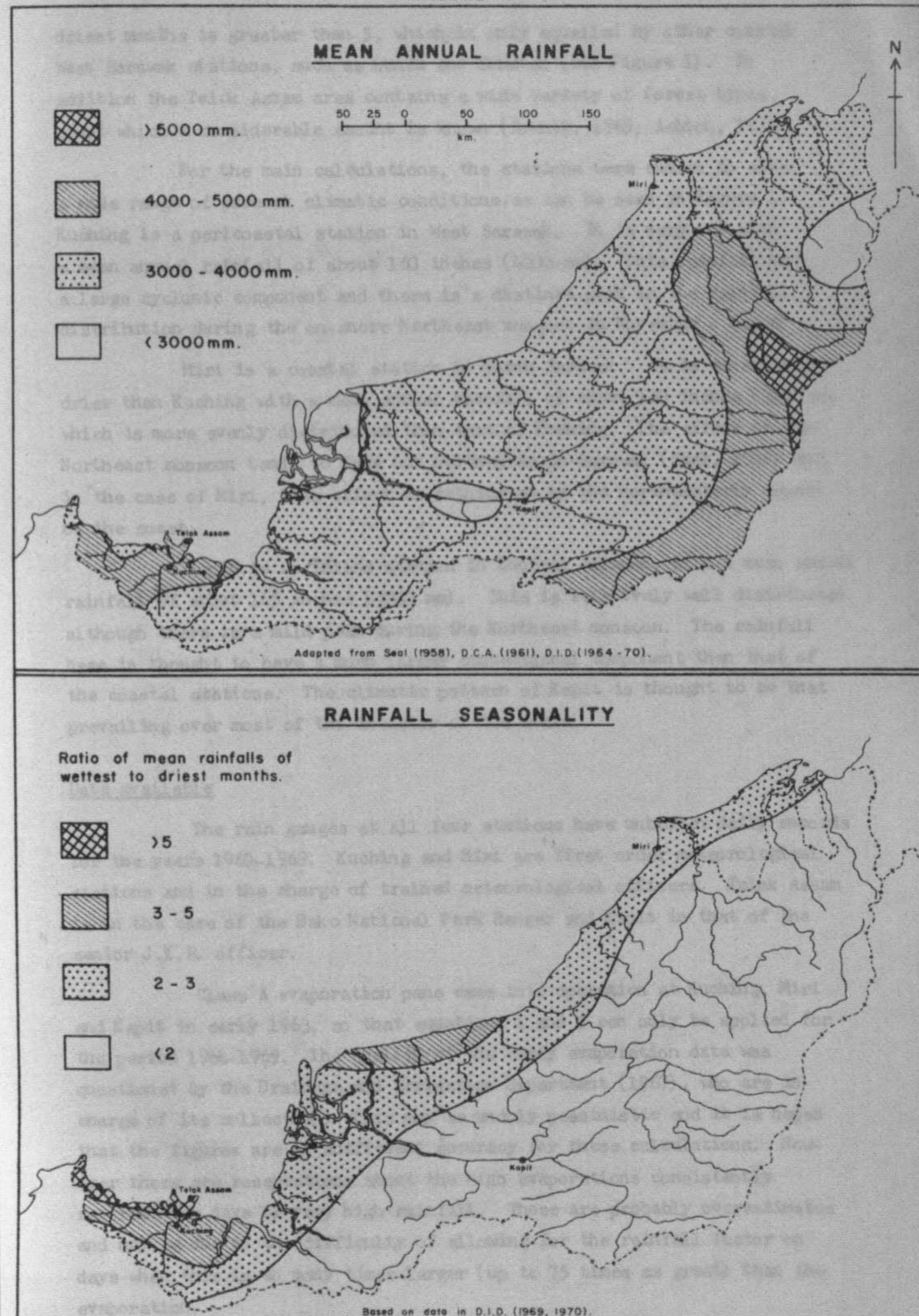
Implicit in Equations 1-5 is the assumption that all precipitation falling on a soil with a moisture deficit enters the soil and that none is lost as lateral runoff (either on, or below, the surface) until the soil has reached field capacity. By not allowing for soils to be wetter than field capacity, i.e. $S_I$ is never negative, it is further assumed that all precipitation in excess of that required to bring the soil to field capacity is lost as runoff or through leaching before the following day. In the case of Kuching, Miri and Kapit the monthly totals of these 'runoff + leaching' losses were calculated, and may give a rough indication of the quantities of water available for pedogenic and geomorphic processes (Arkley, 1967).

The meteorological data used is recorded in inches, so these units were used throughout the calculations and this report, but the approximate metric equivalents are given for the more important results.

## Choice of stations

Telok Assam was chosen because, although it has a heavy rainfall, it has one of the most seasonal distributions of all Sarawak stations. The long term mean of the ratio of the precipitations of the wettest and

FIGURE 1




F.D.S.S. 39  Soil Survey Drawing No. 295  Drawn by Saibiah driest months is greater than 5, which is only equalled by other coastal West Sarawak stations, such as Lundu and Sematan (see Figure 1). In addition the Telok Assam area contains a wide variety of forest types, about which a considerable amount is known (Brunig, 1965; Ashton, 1971).

For the main calculations, the stations were chosen to cover a wide range of Sarawak climatic conditions, as can be seen in Figure 1. Kuching is a pericoastal station in West Sarawak. It is very wet with a mean annual rainfall of about 160 inches (4000 mm). This rainfall has a large cyclonic component and there is a distinct peak in the rainfall distribution during the on-shore Northeast monsoon in November - March.

Miri is a coastal station in North Sarawak. It is considerably drier than Kuching with a mean annual rainfall of about 120 inches (3000 mm) which is more evenly distributed than that of Kuching. The effect of the Northeast monsoon tends to fade out northwards in Sarawak (Seal, 1958) and, in the case of Miri, this effect is reinforced by the northwesterly aspect of the coast.

Kapit is an inland station in Central Sarawak, with a mean annual rainfall of about 145 inches (3700 mm). This is relatively well distributed, although there is a mild peak during the Northeast monsoon. The rainfall here is thought to have a much larger convectional component than that of the coastal stations. The climatic pattern of Kapit is thought to be that prevailing over most of the interior of the State.

Data available

The rain gauges at all four stations have unbroken daily records for the years 1960-1969. Kuching and Miri are first order meteorological stations and in the charge of trained meteorological officers. Telok Assam is in the care of the Bako National Park Ranger and Kapit in that of the senior J.K.R. officer.

Class A evaporation pans came into operation at Kuching, Miri and Kapit in early 1963, so that equations 4 and 5 can only be applied for the period 1964-1969. The quality of the early evaporation data was questioned by the Drainage and Irrigation Department (1967), who are in charge of its collection. This may be unduly pessimistic and it is hoped that the figures are of sufficient accuracy for these calculations. However there are reservations about the high evaporations consistently recorded for days of very high rainfall. These are probably overestimates and may be due to the difficulty of allowing for the rainfall factor on days when this is so many times larger (up to 75 times as great) than the evaporation.

Results

The results of applying Equations 2 and 3 to the rainfall data from Telok Assam for the period 1960-1969 are summarised by years in Table 2.

Table 2

Moisture Stress at Telok Assam, 1960-9

| Year | Annual rainfall (inches) | Days at wilting point | | | |
|---|---|---|---|---|---|
| | | Soil of 6 inches (150 mm) AWHC | | Soil of 3 inches (75 mm) AWHC | |
| | | No. of days | Duration of longest spell* | No. of days | Duration of longest spell* |
| 1960 | 164 | 0 | - | 0 | - |
| 1961 | 172 | 0 | - | 19 | 8 |
| 1962 | 178 | 0 | - | 18 | 12 |
| 1963 | 173 | 24 | 9 | 53 | 12 |
| 1964 | 187 | 0 | - | 24 | 14 |
| 1965 | 152 | 4 | 4 | 25 | 8 |
| 1966 | 133 | 0 | - | 19 | 13 |
| 1967 | 190 | 26 | 20 | 43 | 23 |
| 1968 | 181 | 0 | - | 19 | 8 |
| 1969 | 187 | 0 | - | 9 | 10 |
| Mean | 172 (4400 mm) | 5.4 | | 22.9 | |

* Gaps of one day permitted in these spells.

Table 2 shows that, for shallow soils, moisture stress is likely in most years and that periods of stress lasting 10-20 days can occur several times in a decade. For deeper soils, moisture stress does happen, but is a rarer occurrence.

It is interesting to note how poor an indication of moisture stress is given by the total annual rainfall figures. 1967 was the 'wettest' year (as measured by the total precipitation) and also the 'driest' (as measured by the total number of days of moisture stress). Almost the reverse is true for 1966, which had a low but fiarly evenly distributed rainfall.

Even monthly totals can be misleading. Thus in September 1967 there was 11.87 inches (ca 300 mm) of rain, but this all came in the latter part of the month. The first part of the month was the end of a long dry spell, (the total rainfall for July and August was 5.53 inches (ca 140 mm)) and there were 16 consecutive days at wilting point in September, even on the deeper soils. In contrast September 1966 had only 5.84 inches (ca 150 mm) of rain, but was preceded by a wet month (August 1966 had 12.11 inches (ca 310 mm), and even shallow soils never reached wilting point.

The annual totals of days at PWP (severe moisture stress), days when the soil moisture deficit is greater than 2/3 AWHC (mild moisture stress), and the 'runoff and leaching' losses estimated by applying Equations 2, 4 and 5 to the rainfall and evaporation data from Kuching, Miri and Kapit for the period 1964-1969 are given in Table 3.

<u>Table 3</u>

<u>Annual Summaries of</u>
<u>Soil Moisture Relations at Kuching, Miri and Kapit, 1964-9</u>

| | Kuching | | | | Miri | | | | Kapit | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | P | WP | MS | RL | P | WP | MS | RL | P | WP | MS | RL |
| (i) | Soils of 6" (150 mm) AWHC | | | | | | | | | | | |
| 1964 | 189 | - | 2 | 123 | 120 | - | 34 | 54 | 153 | - | - | 92 |
| 1965 | 131 | - | 3 | 63 | 125 | - | - | 58 | 144 | - | - | 98 |
| 1966 | 146 | - | - | 81 | 127 | - | 13 | 58 | 178 | - | - | 118 |
| 1967 | 144 | - | 23 | 79 | 112 | - | 7 | 47 | 143 | - | - | 83 |
| 1968 | 175 | - | 0 | 114 | 99 | - | 5 | 36 | 146 | - | - | 86 |
| 1969 | 168 | - | 0 | 112 | 122 | - | 51 | 58 | 145 | - | - | 83 |
| Mean | 159 | 0 | 4.66 | 95 | 117 | 0 | 18.33 | 52 | 151 | 0 | 0 | 93 |
| | (4000 mm) | | | (2420 mm) | (3000 mm) | | | (1320 mm) | (3840 mm) | | | (2265 mm) |
| (ii) | Soils of 3" (75 mm) AWHC | | | | | | | | | | | |
| 1964 | 189 | - | 30 | 121 | 120 | 12 | 81 | 54 | 153 | - | - | 91 |
| 1965 | 131 | 3 | 33 | 78 | 125 | - | 36 | 64 | 144 | 2 | 16 | 87 |
| 1966 | 146 | - | 7 | 94 | 127 | 4 | 26 | 63 | 178 | - | - | 115 |
| 1967 | 144 | - | 47 | 85 | 112 | 8 | 28 | 50 | 143 | - | 5 | 83 |
| 1968 | 175 | - | 6 | 114 | 99 | - | 42 | 38 | 146 | - | 3 | 86 |
| 1969 | 168 | - | 0 | 113 | 122 | 16 | 54 | 68 | 145 | - | - | 84 |
| Mean | 159 | 0.5 | 20.5 | 102 | 117 | 6.67 | 44.5 | 57 | 151 | 0.33 | 4 | 91 |
| | (4000 mm) | | | (2600 mm) | (3000 mm) | | | (1650 mm) | (3840 mm) | | | (2210 mm) |

Notes:
P = Precipitation, to nearest inch
RL = Runoff and leaching, to nearest inch
WP = Number of days soil is at wilting point
MS = Number of days AWHC > soil moisture deficit $\geq \frac{2AWHC}{3}$

The poor correlation between the total annual rainfall and the number of days of moisture stress noted in Telok Assam calculations is again apparent. Thus, at Kuching, vegetation on a shallow soil experienced almost as many days (30 against 33) of moderate moisture stress in the wettest year (1969) as it did in the driest (1965), even though the difference in rainfall is almost 60 inches (1500 mm). Similarly a deep soil at Miri experienced 34 days of moisture stress in an intermediate rainfall year (1964) but only 5 in the driest (1968), the difference in rainfall being over 20 inches (500 mm).

As at Telok Assam, the monthly rainfall totals, taken individually, can also be misleading, as can be seen in Table 4.

Table 4

Monthly Rainfall and Moisture Stress on a Shallow Soil, 1965

| | Kuching | | | Miri | | | Kapit | | |
|---|---|---|---|---|---|---|---|---|---|
| | P | WP | MS | P | WP | MS | P | WP | MS |
| Jan. | 15 | 3 | 6 | 25 | - | 3 | 10 | 2 | 2 |
| Feb. | 27 | - | - | 10 | - | 11 | 8 | - | 4 |
| March | 14 | - | - | 12 | - | 5 | 17 | - | - |
| April | 11 | - | - | 10 | - | - | 8 | - | - |
| May | 6 | - | - | 7 | - | - | 14 | - | - |
| June | 9 | - | - | 8 | - | - | 7 | - | - |
| July | 2 | - | 17 | 5 | - | 2 | 3 | - | - |
| Aug. | 10 | - | 3 | 5 | - | 9 | 13 | - | 6 |
| Sept. | 5 | - | - | 5 | - | 6 | 11 | - | - |
| Oct. | 6 | - | 7 | 11 | - | - | 20 | - | - |
| Nov. | 8 | - | - | 12 | - | - | 13 | - | - |
| Dec. | 18 | - | - | 15 | - | - | 24 | - | - |

Notes: P = Precipitation, to nearest inch

WP = Number of days soil at wilting point

MS = Number of days AWHC > soil moisture deficit $\geqslant \frac{2AWHC}{3}$

In several cases, in this year and in others, the rainfall of the preceding month gives a better indication of possible moisture stress than that in the month itself. Thus, at Kapit, the driest month (August) received 13 inches (330 mm) of rain, but in July there were only 3 inches (80 mm) of rain.

January 1965 is an exceptional month at all stations, especially at Miri, where there was moisture stress despite a monthly total rainfall of 25 inches (630 mm). In all three stations the rainfall was very unevenly distributed, with practically none in the second half of the month. In addition, at Kuching, the evaporation was exceptionally high, totalling almost 10 inches (250 mm) for the month (D.I.D., 1970).

Discussion

Prediction from meteorological data of soil moisture conditions is a poor substitute for actual measurements (Webster and Beckett, 1969), especially with a model as simplicistic as that used here. The assumptions that a soil is never wetter than field capacity at the beginning of the day that surface infiltration rates never limit percolation into a soil with a moisture deficit (Guha, 1969), and that the decrease in evapotranspiration is abrupt at an arbitrary moisture content, all represent departures from reality. These deficiencies notwithstanding, several interesting points arise from the results.

The most important is that vegetation on the deeper soils is rarely subject to moisture stress. Using Equation 3 it seems that there were only two years in the decade when the deeper soil reached PWP at Telok Assam. Using the more elaborate model of Equations 4 and 5, PWP appears never to have been reached on the deeper soils at the other three stations during 1964-1969. Mild moisture stress occurred for short periods in most years at Miri but was rare at Kuching and unknown at Kapit.

On the shallower soils, moisture stress is much more frequent. Thus, at Telok Assam and Miri, severe drought is an almost annual event and, at Miri, mild moisture stress is experienced for between 1/10 and 1/4 of the year. True drought was rare at Kuching but mild stress occurred almost every year. At Kapit mild moisture stress was experienced in only 3 out the 6 years and true drought was rare.

Tables 2 and 3 show that vegetation growing on shallow soils in Sarawak, especially in coastal areas, would have a competitive advantage if it were able to reduce evapotranspiration and postpone the onset of moisture stress. For this finding to accord with Brunig's suggestion that the kerangas forest is more xerophytic than the Mixed Dipterocarp Forest there would have to be a difference in effective depths between the soils on which the two forest types are found. At first sight, this is apparently not the case, and the kerangas soils often have as deep, or deeper, sola than the Red Yellow Podsolic and Skeletal soils under the MDF. However most of the deeper soils under kerangas are humus podsols, and these often have extremely indurated A2 horizons (Andriesse, 1969) which are impenetrable to roots, so that rooting depth is much less than solum depth. Conversely the shallowness of the many MDF soils is illusory and the shallow sola overlie soft weathering rock which is penetrated and exploited by tree roots.

Comparison between the stations shows that the slightly lower but better distributed rainfall at Kapit is physiologically more effective than that of the wetter West Sarawak stations. As can be seen from Figure 1, the Kapit type of moisture regime is thought to prevail over most of the country. The greater incidence of droughts in the coastal areas is due to the lower frequency of convectional rainfall, compared with the interior areas (Andriesse, 1971).

The 'runoff and leaching' figures in Table 3 are speculative but they may be of the right order. Working on the large outcrop of poorly consolidated Tertiary sedimentary rocks and combined with considerable recent tectonic uplift, this large quantity of geomorphologically effective water gives rise to the very active erosion that is a feature of the Sarawak landscape.

There is an area of experimental engkabang (illipe nuts) plantations about 6 miles (10 km) from the Kuching station. These yield fruit irregularly and it has often been said that flower initiation requires a period of moisture stress. Within the period 1964-70, the plantations yielded fruit in 1968 and 1970. The 1968 crop fits in well with the 'dry spell trigger' hypothesis, as 1967 was the driest year of the period at Kuching and there were more days of moisture stress than in any other year. Moreover almost all of these days occurred in a period of less than two months during July and August. During August vegetation on shallow soils was subject to mild stress for 25 days. However the 1970 crop does not fit the hypothesis so well, as 1969 was the only year out of the 6 in which there was no moisture stress at all, even on shallow soils. The only indication of a dry period is the 'runoff and leaching' figure of only 0.74 inches (15 mm) in June.

Before drawing any conclusions it must be remembered that we only have records for the years fruit was actually harvested. There may have been other years in which the trees flowered but did not set fruit or in which the flowers or fruit were destroyed by wind or other agencies. However it seems that the relationship between climate and phenological changes may be more complex than was thought, and needs to studied over a longer period.

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