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RAIN-FALL IN MALAYSIA
A Study of its Occurence with Tables of Probability of Rainfall at Selected Stations, and an Introduction to Hydrology in Rubber Plantations

Rubber Research Institute Of Malaya.

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RAINFALL IN MALAYSIA

A Study of Its Occurrence,
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Hydrology in Rubber Plantations

by
P. R. WYCHERLEY

RUBBER RESEARCH INSTITUTE OF MALAYA

CONTENTS

INTRODUCTION

Water is essential for life. An adequate balance of moisture in the soil is especially important for the success of planting. Excessive rain can be a hindrance. The main object of this Manual is to assist in the selection of favourable seasons for planting.

Malaysian rainfall data have been presented previously by various research workers (DALE, 1959) and meteorological organisations in Malaya (1957) and Borneo (1959) as tables or diagrams of the monthly Means. Authors have divided Malaya (Western Malaysia) and Sabah into rainfall regions according to the seasonal variation in mean precipitation throughout the year and, to a lesser extent, the total annual rainfall with a passing reference to diurnal distribution (DALE 1959, WYCHERLEY 1963a and b). The publications just mentioned are of limited availability today, therefore tables and diagrams summarising previous records have been prepared for circulation among the Malaysian planting community. The data indicates the probability of obtaining certain amounts of rainfall each month after the manner used first for Sabah (WYCHERLEY, 1963b). Although the general conclusions of previous studies are thereby little altered, this presentation is preferred because Mean monthly rainfall figures are liable to give a distorted estimate of the probable rainfall, especially in critical cases.

Weather may be defined as the integration of ambient physical conditions at a given place and time. Climate is an extension of this concept to include the variations through the year. Throughout Malaysia, rainfall shows more obvious variation with season and locality than do temperature, humidity, sunshine and wind speed. Mean temperature declines with elevation; sunshine increases with proximity to the coast and with latitude; wind speeds drop in the more secluded lowlands. Seasonal variation in these parameters is relatively small, although in combination, e.g. as potential evaporation or effective temperature, they may display more constant or significant differences. Such differences are discussed here only as far as rainfall requirements are concerned. The major variable receiving attention is rainfall itself. The manner in which the rather scanty rainfall data available can be used to the best advantage will be appreciated more easily if the conditions leading to precipitation are described in relation to the prevailing winds.

TYPES OF RAINFALL

The types of rainfall have been described by WATTS (1955) and DALE (1959). *Orographic* rainfall (from *oros*, a mountain) results from the cooling of moisture-laden air when winds which have crossed the seas are forced to rise over the land; the heavy rain in the hills of the East Malayan Range during the North East Monsoon is an example of this type. Under Malaysian conditions the warm saturated air need not rise very high to bring about precipitation. Monsoon rain along coasts increases inland from relatively light rain, if the coast is flat, to torrential downpours in the higher hills. It decreases on the lee side, which may experience a Foehn or drying effect.

Boundary rain falls from clouds forced upward where air streams converge or a strong current presses against a relatively static body of air. This occurs in advance of a monsoon, in particular along the southern boundary of the North East Monsoon, whose rate of movement slackens as it moves southward across the South China Sea and builds up against the Doldrums (the still zone then lying a little south of the equator) or against the Southern Trade Winds from off Western Australia; in the latter case the two air streams may be mutually diverted east or west. The boundary of the monsoon may be stationary or even retreat temporarily in the course of its approach to the equator. The very heavy rains along the Northern coast of Borneo, especially in Sarawak, originate in this way.

Instability rain results from rising convection currents due to the warming of the land in post-equinoctial periods of slack variable winds between monsoons. This accounts for April being the month with the heaviest rainfall along the junction of the plains and foothills of western Malaya, see for example Selama, Taiping, Trong, Ipoh, Batu Gajah, Gopeng, Kampar, Tapah, Kuala Lumpur, Klang, Kajang and Labu.

THE WINDS

Rainfall in Malaysia is determined by global air movements and it is convenient to open the discussion on these with the cooling of the Asian land mass after the autumnal equinox. An area of high atmospheric pressure develops with its centre in Mongolia, from which air flows outward acquiring a clockwise motion owing to the earth's rotation. Winds thus generated are known as the North East Trades off the China coast and as the North East Monsoon over southern and south-eastern Asia. When these winds reach Malaysia, they are laden with moisture from the South China Sea. The North East Monsoon reaches the north-eastern parts of Malaya first, sometimes as early as the latter part of October, but usually in November, and strikes along the eastern coast progressively later as it moves south. By January the winds veer to the east over Malaysia, although at the western end of the Sarawak coast they are almost northerly as the air stream is diverted to merge with the westerlies south of Borneo.

Sarawak receives intense boundary rain during the latter part of this period. All places exposed to the North East Monsoon experience heavy rainfall. There is a decline in precipitation in February, although in parts of Malaya's East Coast it is only temporary because more rain falls during the final slackening of the North East Monsoon in March. Those parts sheltered from this monsoon receive little rain, in particular north-western Malaya may suffer long dry spells during December, January and February (Dale, 1960); especially February is liable to be very dry on the western coast of Sabah as the monsoon veers east behind the Crocker Range.

By April, the winds are slack and variable, mainly from local convection with an easterly drift over most of Malaysia, but the first westerlies may appear on the western coast of Malaya reinforced sometimes by sea breezes. April is a period of instability rain not only in the west of the Main Range of Malaya but also in most parts of Sarawak.

During May and June, the South West Monsoon develops and reaches progressively later areas further north and east in southern Asia. It is generated by high pressure over the south Indian Ocean during winter in the southern hemisphere and drawn towards the low pressure area over the Himalayas. Pressure is also high over the Australian sub-continent and south-easterly winds blow towards South East Asia until they are deflected over Borneo and southern Malaya by the South West Monsoon from across the Indian Ocean. Thus the winds are south-westerly over the northern half of Malaya, south or south-easterly over southern Malaya and most of Sarawak, but are turned to south westerlies again over most of Sabah. This rain-bearing wind is termed the South East Monsoon in most parts of Sarawak (as on the China coast).

The southerly monsoons bring fairly heavy rain to a number of areas such as the coast of Kedah and around Malacca, the latter being the boundary of the two main air streams. But the rain is not very persistent except in central Sarawak, because much of Malaysia is screened by the mountains of Sumatra and Southern Borneo. Local areas of moderate rainfall occur on the east coasts of both Malaya and Sabah especially during July and August. These monsoons slacken off in August.

After the September equinox winds are again weak and variable, being mainly westerly over Malaya and southerly over Borneo. Instability rain descends on most parts of Malaya and Sarawak. Meanwhile the North East Monsoon is gathering.

An account such as this indicates only the general pattern and there is considerable local variation. Relatively small differences in the direction of a monsoon may determine whether rain falls on a particular point or is intercepted by mountains. The areas where air streams meet and the degree to which they are deflected (or sometimes reversed) depend to a large extent on happenings in the distant air masses over the continents and oceans. Yet, this may result in very heavy precipitation of boundary rain locally or none at all. During January for example, less than one quarter of an inch of rain was recorded at Limbang in 1950 but nearly thirty-six inches in 1918. Hence, there is need to express rainfall data in a manner which shows the variability in, and the probability of, precipitation.

RAINFALL REGIONS

It is convenient to divide a country into regions with distinctive patterns of rainfall. DALE (1959) divided Malaya into the following five regions.

North West Malaya, which has peaks in rainfall during both the post-equinoctial transition periods between monsoons, low rainfall during the North East Monsoon, and moderate precipitation during the South West Monsoon. The northern plain of Kedah and Perlis receives less rain than the Kedah Peak, as well as the mountainous parts of Penang and south Kedah.

West Malaya, which has peaks in rainfall during the transitional periods; often the first (April) is more intense but of shorter duration than the second (October and November) during which there is more rain in total. Fair amounts of rain are received during the North East Monsoon except in February. The period of the South West Monsoon has least rain, especially in July.

Port Dickson–Muar Coast, which sometimes has rain during the first transitional period. Usually there is a steady build-up during the South West Monsoon to a maximum during the second transitional period, followed by little rain during the North East Monsoon.

South West Malaya, which has a rather equitable distribution of rain throughout the year. Rainfall is low inland, and increases towards the coast.

East Malaya, which has heavy rainfall during the North East Monsoon and light rain during the rest of the year.

The stations considered in this Manual are numbered so they correspond, in sequence, to these regions. The boundaries are not sharp and some stations have rainfall patterns intermediate between those characteristic of the main regions. The stations numbered 1 to 7 are in the North West Region; 8 to 11 are shown as North West Region in Dale's map but are considered to be in the West Region in this assessment; 12 to 43 are in the West Region; 44 to 48 are in the Port Dickson–Muar Region; 49 to 62 are in the South West Region; 63 to 73 are in the East Region.

Following the approach developed elsewhere in this Manual, the most probable rainfall rather than the average should be considered. On this basis not only would the southern boundary of the North West Malaya Region be drawn a little further north, but the distinction of the South West Malaya Region from the West Malaya Region becomes difficult to sustain. Of the fourteen stations (49 to 62) in Dale's South West Region, eleven have distinct troughs in the modal rainfall in February, eight in July and about half display definite peaks in April and/or November; October shows strong peaks in nine cases, the majority of the other stations show weak troughs or peaks respectively in these months. It would seem that the pattern is essentially the same in the South West Region as in the West Region, only the amplitude of the seasonal variation is somewhat less in the South West Region (where the rainfall in the wettest months is usually about three times that in the driest) than in Dale's West Region (where the rainfall in the wettest months is about four times that in the driest). Therefore in the modified map of Malaysian Rainfall Regions (*Figure 1*) the South West Region is omitted and the boundary of the North West Region is adjusted.

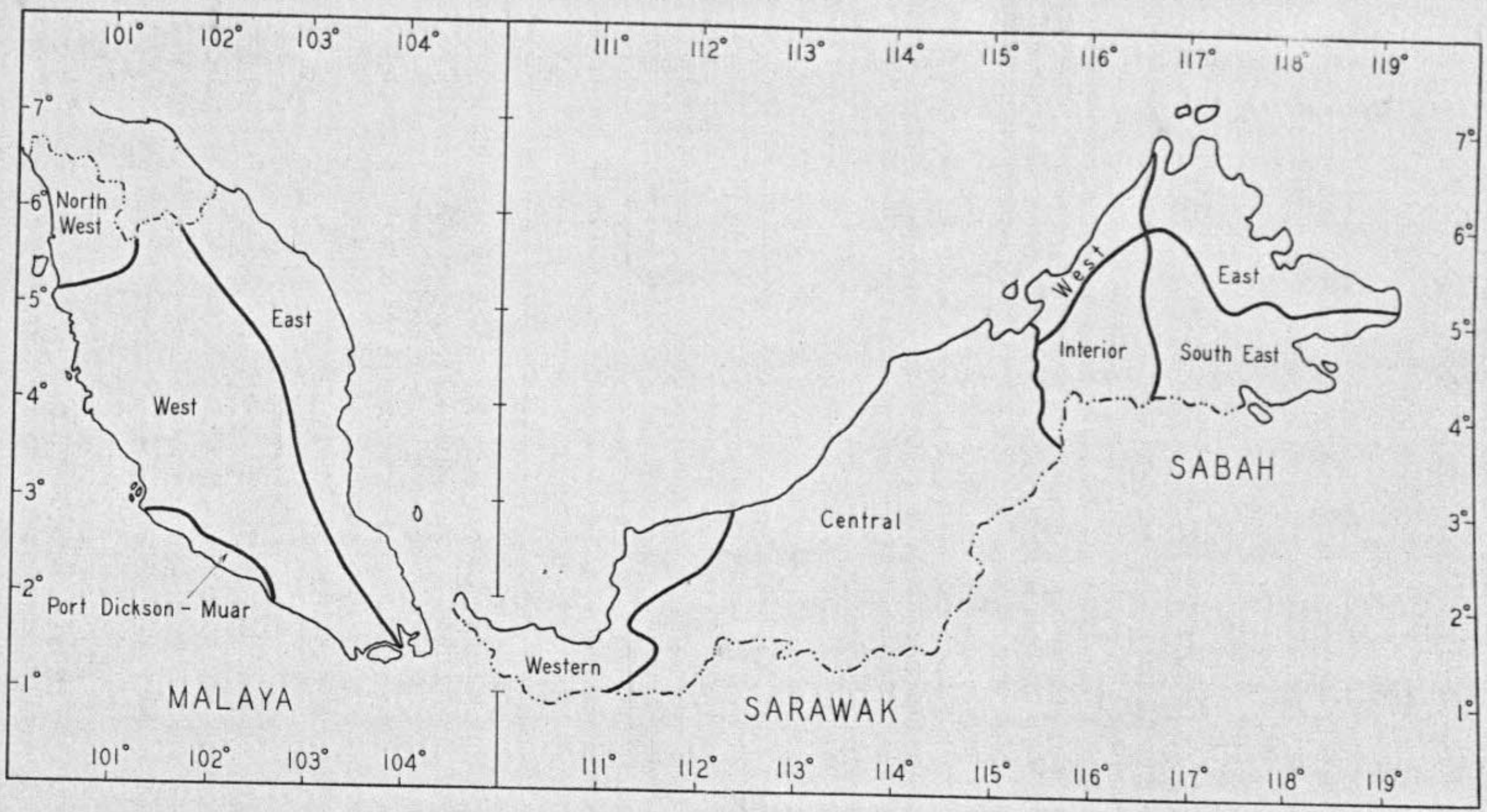

Figure 1. Rainfall Regions of Malaysia

Rainfall Regions do not appear to have been proposed for Sarawak hitherto, most writers being content to remark that precipitation is high. Indeed, for several months excessive rain is a greater problem than an inadequacy in most parts of Sarawak. Therefore in considering the two Rainfall Regions proposed for Sarawak according to the distribution of rainfall throughout the year, it should be noted that the significance is largely inverted compared with most of Malaysia — the peak rainfall months in Sarawak are often too wet.

Western Sarawak, which has rain throughout the year but a very definite peak during the North East Monsoon in December and January, rarely beginning in November but frequently extending into February in the more western portion. Stations 74 to 79 are in this region, comprising the coastal plain of West Sarawak. Simanggang (78) is transitional between this and the Central Sarawak region, if modal values are examined.

Central Sarawak, which has a tendency towards a bimodal rainfall distribution with moderate troughs before or about the equinoxes. Stations 80 to 83 are examples. The troughs in modal rainfall are more marked for Miri (81). However, at some stations the rainfall is almost uniformly high throughout the year; a few others have affinities with the Western Region. This large area, comprising all portions of Sarawak not assigned to the Western Region, could probably be divided further if more data were available.

Rainfall Regions suggested for Sabah (WYCHERLEY, 1963b) are followed here with minor modifications. Like Malaya, but in contrast to Sarawak, Sabah has some districts with relatively low rainfall.

West Sabah, which has minimal rainfall in or about February, becoming fairly heavy by April (south-western portion) or June (north-eastern portion), which level is held or slightly relaxed before rising to maximum precipitation in October to December. The north-eastern portion of the West Region is protected from the full force of the North East Monsoon as it veers east and is for the most part too far north to experience much boundary rain, hence the rainfall normally begins to diminish in November or December. The later start and earlier decline of the main rains in the north eastern portion results in a distinctly lower annual total than at the south-western end. The transition between these two extremes is gradual and there is no definite boundary to separate the Region into two distinct parts. Stations 84 to 89 are in this West Region lying to the west of the Crocker Range. Bundu Tuhan (102) is a high altitude example.

East Sabah, which has heavy rain throughout the North East Monsoon; during the rest of the year precipitation is low in the north and moderate elsewhere. Stations 90 to 94, which lie east of the James Brooke and Crocker Ranges, are in this East Region which extends as far as the hills behind the southern coast of the Dent Peninsular.

South East Sabah, which has low to moderate annual rainfall without marked variation throughout the year. Minimum precipitation occurs usually in the period February to April and the maximum in August to November. Lahad Datu (96), on the northern shore of Darvel Bay, receives its peak rainfall in January and sometimes heavy rain during February and March also, although these can be dry months, depending on how far the force of the North East Monsoon is spent as it veers east. Most of the other stations have a minor rise in rainfall during January. The boundary with the Interior Region is poorly defined owing to lack of data.

Interior Sabah, which, except for the eastern parts about Pensiangan, Sapulut and Tulid, is enclosed by mountain ranges and receives relatively little rain. There are two peak rainfall periods; the first within the period April to June is normally the heavier and is followed, after a drier period, by rain in September and October (rarely in August or November). Moderate rain in January is usually followed by a minimum in February. Stations 98 to 101 are representative.

State, District or Divisional boundaries in Borneo often follow watersheds, resulting sometimes in a convenient correspondence with Rainfall Regions.

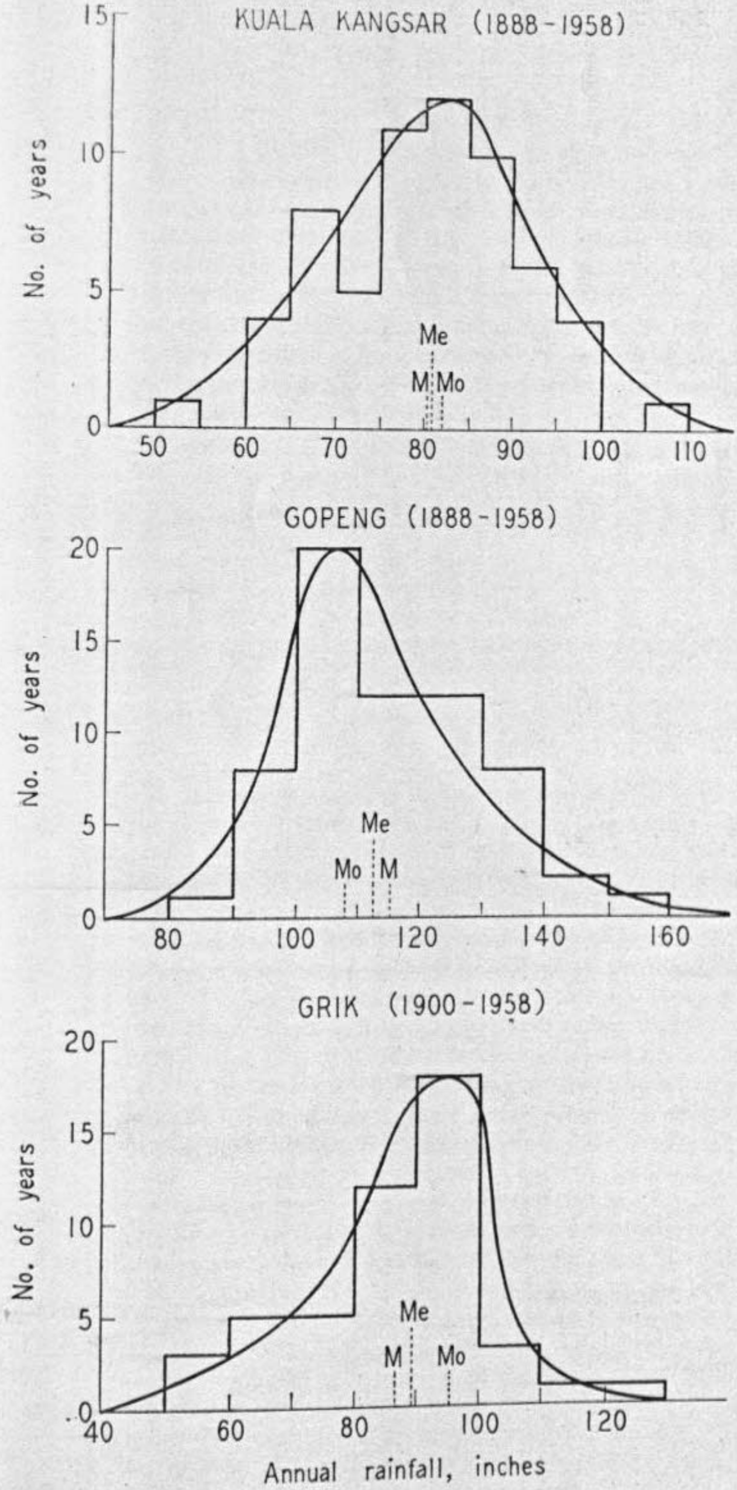

Figure 2. Frequency histograms of annual rainfall at Kuala Kangsar, Gopeng and Grik (M—Mean, Me—Median and Mo—Mode).

VARIATION IN RAINFALL FROM YEAR TO YEAR

There is variation from year to year in the total annual rainfall and in the precipitation during each month at any place. The average precipitation can be misleading for reliable prediction of rainfall. Firstly, a few relatively high values can inflate the Mean, especially in low rainfall months (for example, this is the case for Sungai Patani, Tikam, Labu, Buloh Kasap, Rengam and Keningau in February and for Sitiawan, Kampar, Teluk Anson, Kuala Kubu Baharu and Batang Berjuntai in July). Secondly, the actual values may be widely dispersed or grouped closely about the Mean; in the former case, rainfall expectation being less reliably predictable than in the latter, contrast respectively the following months with the same mean precipitation:

January and August	—	at Kampong Kroh,
March and September	—	at Sitiawan,
February and May	—	at Bagan Pasir,
February and June	—	at Tikam,
May and April	—	at Tikam
March and May	—	at Banting,
November and October	—	at Perhentian Siput,
and December and October	—	at Kota Belud.

FREQUENCY DISTRIBUTION

One method of studying the variation in rainfall is to make a frequency histogram showing the number of years in which the precipitation fell within a given range. Frequency histograms for the annual rainfall at Kuala Kangsar, Gopeng and Grik are given in *Figure 2*. The arithmetic mean or average is indicated by M in each case. The peak of the frequency distribution curve, that is the value which occurs most often, is called the Mode and is indicated by Mo. The Median, indicated by Me, is obtained by arranging all values in array from the smallest to the largest and taking the middle one, that is the one with equal numbers of values on either side. There are equal chances of obtaining higher or lower values than the Median. In compiling these tables a curve has been drawn for each month for each station of the records in array, e.g. *Figure 3*, and the frequency a given number of inches of rain or more has been recorded has been read off and the 50% frequency taken as the Median. The Modes in these tables have been determined by a graphical method similar to that illustrated in *Figure 2*. In each case the range was divided into 12 to 20 frequency classes according to the number of records available, the position of the Mode in the most numerous class being estimated by weighting with the relative sizes of the adjacent classes. Graphical methods of determination have been adopted, because the fewest assumptions are involved and there is less risk of biasing the conclusions by a few abnormal records. It should be noted that although the annual Mean is the sum of the monthly Means, the Median and Modal values do not add up in this way.

If the values are balanced equally about the mean in a particular manner, the distribution is said to be 'normal' and the Mean, Median and Mode are the same. The Kuala Kangsar annual rainfall (*Figure 2*) approximates to this. The practical implications of deviations from normal taking the form of either a tall and narrow peak or a flattened curve, are covered in the previous section, and in the frequency tables. When the distribution curve appears lop-sided owing to many values which do not deviate much from the Mean on one side being balanced by relatively few values which deviate more on the other, the distribution is said to be skewed. If the abnormality is in the form of a few very high values, the tail stretching away to the right, then the skew is said to be positive and the Mode is exceeded by the Median, which is exceeded by the Mean, Gopeng annual rainfall in *Figure 2* provides an example. Conversely a tail to the left is called negative skew and the Mean, Median and Mode are in the opposite order, illustrated by Grik in *Figure 2*.

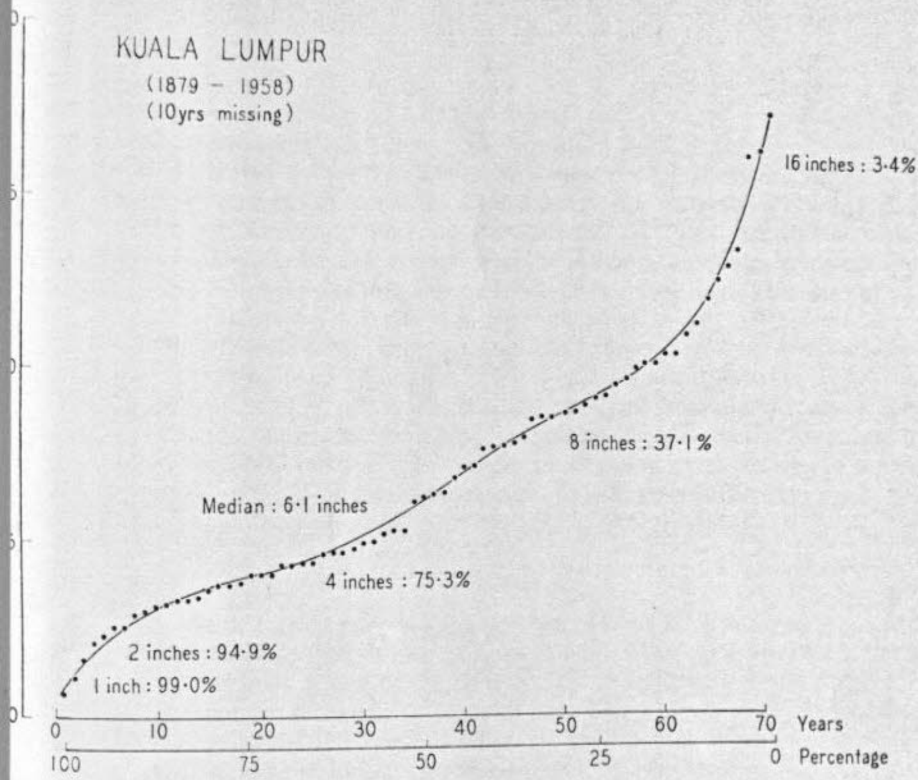

Figure 3. Curve to determine Median rainfall and the percentage frequency certain amounts of precipitation are exceeded.

equency distributions of annual rainfall are usually normal, occasionally positively , but very rarely negatively skewed; Grik is the only marked example of negative skew nual rainfall detected in the Malaysian data. The frequency distributions for rainfall any particular month are sometimes normal but more often positively skewed, only nally negatively skewed. Where distributions are positively skewed the Mean is an timate of the probable rainfall. The distribution of monthly rainfall is sometimes al, that is with two peaks. This is most common at stations receiving rain during nsoons, which may be early or late, heavy or light, subject to boundary effects or to behind mountains.

TABLES AND MAPS

ch month the tables show the percentage frequency which each given quantity of rain e has fallen. The levels of rainfall considered are in geometric series, namely 1, 2, 4, r 32 inches of rain during the month. The Mean, Median and Mode are given for nonth and for the annual rainfall. Two values of the Mode are given for bimodal utions. A minus sign before a Modal value, or a plus after it, indicates a weaker t lower or higher values respectively.

ne accuracy of these estimates is greatly influenced by the number of records available; mple if there are records for only 20 years the figure for each year contributes 5% to rcentage frequency occurrence, but only 2½% if there are data for 40 years. At least ears' records are desirable for these purposes, but in many areas it has been necessary to accept less. The sources are the '*Hydrological Data, Rainfall Records, 1879—1958*' published by the Drainage and Irrigation Department, Federation of Malaya, 1961 and the '*Rainfall Statistics of the British Borneo Territories*' published by the Department of Civil Aviation and Meteorological Services, British Borneo Territories, 1961. When more records are available it will be desirable to revise the tables completely by computer methods.

Maps of Median and Modal rainfall have been drawn. These of necessity must be largely by interpolation, the calculated values for the relatively few stations with sufficient records being supplemented by fragmentary records from elsewhere and likely trends inferred from climatological and topographical data such as wind direction and the location of hills. To estimate the probability of obtaining a certain rainfall in any situation, both the maps and the tables for nearby stations should be considered in conjunction with the general discussion of rainfall in Malaysia given above. The question of how much rain is desirable for particular operations is discussed below.

NUMBER OF RAINY DAYS PER MONTH

For certain purposes the number of rainy days per month might be a better or more reliable measure than inches of total rainfall (NARAYANAN, 1966). A rainy day is defined in this manual as one on which at least one hundredth of an inch of rain falls. Other definitions are used elsewhere; some of the older records gave the number of days in the month on which 0.01, 0.5 or 2.0 inches fell, but the bulk of the published data available gives only total inches precipitation month by month. An attempt was made to find a general relationship by plotting the number of rainy days against the total rainfall for 60 consecutive months at nineteen stations. In every case there was a strong positive correlation; for many stations this was improved if the logarithm of the rainfall was used. However, there is considerable variation especially in the rainfall bracket four to eight inches, in which the number of rainy days can show three-fold variation. Fitted curves for each station were drawn on one graph and those of similar form were grouped together as in *Figure 4*, where five bands covering the area of the individual curves in each group. The variation for any station is even wider than the band in which it is placed. With the exception of Sandakan, in band 3, all the stations with more than 100 inches of rain per year are in bands 1 and 4. Apart from this partial classification, with its one exception, it is difficult to find any characteristic (Rainfall Region, ratio of highest to lowest monthly rainfall or the number of months receiving above-average rainfall) which will separate the stations in bands 1 and 4, or in bands 2, 3 and 5. Therefore, except for those individual stations for which curves have been drawn, it is impracticable to use this method to predict the number of rainy days per month from total monthly rainfall.

RAINFALL INTENSITY

The curves in *Figure 4* can be used to estimate the average intensity of rainfall in inches per day at various rainfall levels and stations, taking the central values for each band as follows:

RAINFALL INTENSITY, AVERAGE INCHES PER DAY

Inches per Month	½	1	2	4	8	16	32
Band 1	0.05	0.08	0.12	0.22	0.37	0.66	1.08
2	0.07	0.09	0.14	0.22	0.37	0.60	
3	0.09	0.12	0.17	0.25	0.39	0.63	
4	0.10	0.14	0.18	0.28	0.46	0.73	1.14
5	0.20	0.22	0.27	0.33	0.44	0.62	

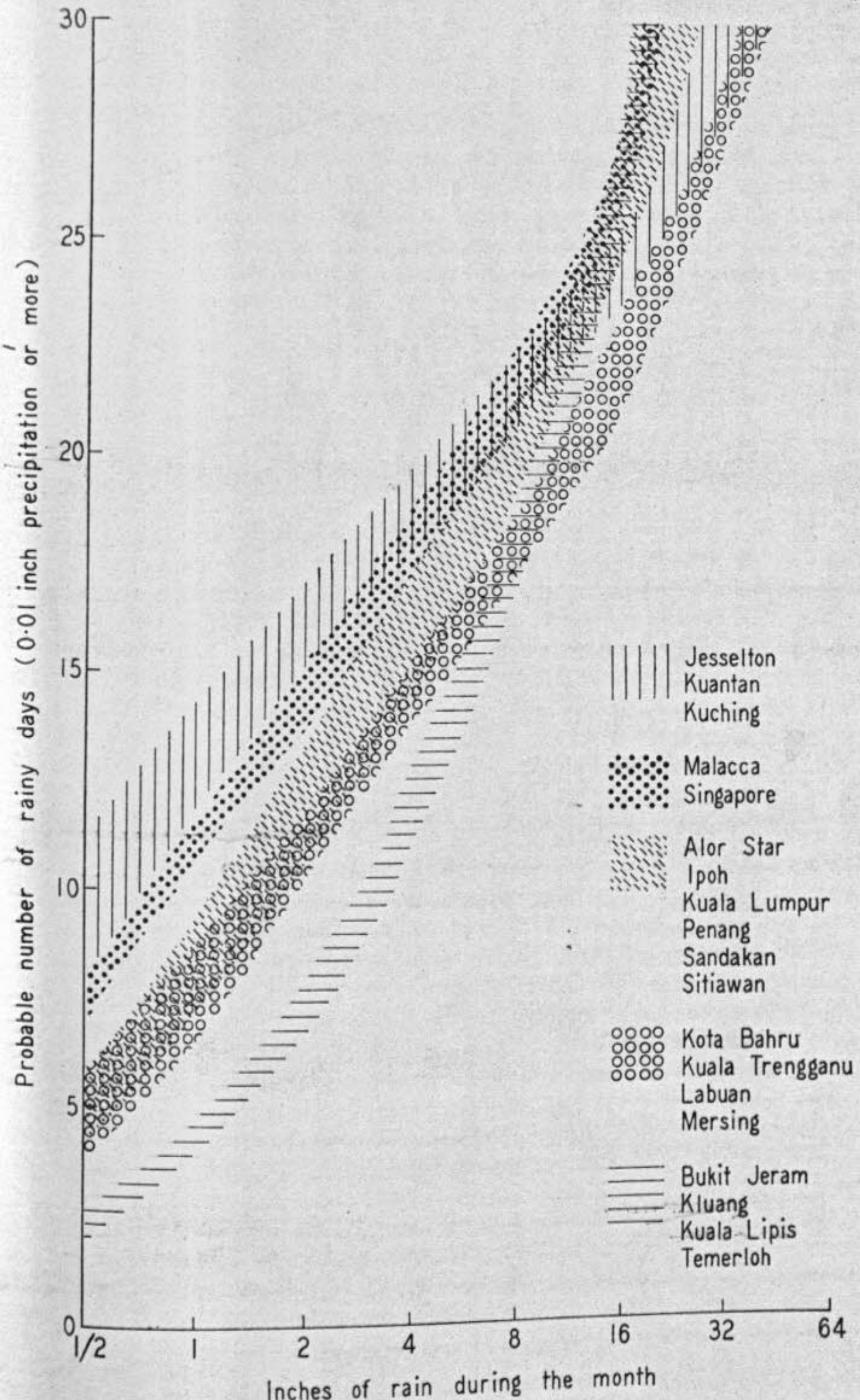

Figure 4. Relationship of the Number of Rainy Days to Inches of Rain in the Month

The local intensity of precipitation during rainstorms is discussed in the Appendix to the '*Hydrological Data*' for Malaya (D.I.D., F.o.M. 1961) and by CHARLTON (1961). The highest rates probably occur during instability thunderstorms and are not maintained for long; the maximal rate of about 8 inches per hour at Kuala Lumpur had a duration of not more than 15 minutes; but relatively low intensities, about one tenth of an inch per hour, may be sustained for four to five days, especially on the east coast of Malaya.

WATER BALANCE

One approach to how much rain is needed for planting operations is to assess water loss by evaporation, including transpiration by the vegetation, and to draw up a balance against gains by precipitation. The water-holding capacity of the soil is the maximum water which can be stored in the soil. This simple model is complicated by several factors, of which the most important is probably run-off, that is, rain which does not soak into the soil but runs off over the surface.

The investigation of the eventual destiny of precipitation is called hydrology and PENMAN (1963) has given a classic summary of the role played by vegetation in modifying what happens to rain after it has fallen. 'Interception' is the retention of water on vegetation and other above ground structures. It is unimportant in clearings for plantings and is omitted from this discussion. Rain reaching the soil surface is divided by Penman as 'run off' and 'infiltration' into the soil. Water lying indefinitely on the soil surface in pools is not considered further, in any case water-logging is not tolerated by crops like rubber.

Transpiration by vegetation increases the demand for water and the consequent stress enhances absorption of water by the soil. Vegetation, including the litter on the soil surface, reduces run-off in various ways; for instance, by breaking the force of rain drops that would otherwise shatter soil particles into fine material which would clog the soil interstices. Moreover litter filters out such debris produced by the shattering or slaking effects of rain on soil. Plant roots, associated soil organisms and humus from litter also improve soil structure and permeability. A progression from a favourable proportion of infiltration to conditions of rapid, heavy run-off and concomitant erosion may be discerned approximately in the following order: forest with litter is better than trees without litter, established grassland is more favourable than young grass, burnt areas, row crops with cultivated soil, or bare soil. There are some preliminary indications that rubber plantations with a good canopy or adequate ground cover plants do not compare unfavourably with natural forest. However, under conditions of high precipitation the soil may be saturated and a steady state of percolation and transpiration may be reached; rain in excess of this must run off irrespective of the nature of the vegetation. Even so, vegetation can slow down the rate of discharge thus reducing the erosive effects. Erosion results not only in the loss of valuable top soil from the plantation, but in silting of rivers with consequent risks of flooding.

PROPORTION OF RUN-OFF

Returning to the problems of rubber planting, the run-off is worst where the trees have been felled, cleared and burnt, the soil cultivated and laid bare. Thus when water is most needed to establish young plants, conditions will encourage run-off and a considerable proportion of the precipitation may not be added to the available soil water reserves. The drainage rate is much affected by topography and soil type. The water-holding capacity is usually improved by increased organic content of the top soil. The role of cover plants, contour terraces and silt pits in water conservation is evident and important.

How much water will be lost to the plants by run-off is difficult to assess; very few records are available from areas corresponding to Malaysian lowland agricultural conditions. The water measured in river-flow or collected from catchments for public water supplies, irrigation or hydro-electric schemes includes both the surface run-off and water which has drained by percolation through the soil into streams. This total run-off may be equated with the rainfall less evaporation (including transpiration by plants) and deep percolation. It seems likely that about one-third to one-half of the rainfall reaches rivers, reservoirs or the sea in this way under Malaysian conditions. The proportion which runs off may be even more than one-half in severely disturbed catchment areas or clearings; heavier erosion burdens this with debris and renders the increased yield of water less suitable for use by public utilities and it also silts up reservoirs.

The surface run-off, which does not contribute to soil water reserves and is available to plants only if intercepted, is usually assessed by comparing the run-off from a catchment of known size during individual storms of measured intensity with the usual or basic rate of total run-off (CHARLTON, 1962; OW, 1964). The initial rate of surface run-off depends on surface conditions and the antecedent degree of saturation of the soil. The amount of run-off will increase as the soil is wetted, and surface run-off may vary from nil to a large proportion of storm downpour. Possibly one quarter or more of the total rainfall may be dissipated in surface run-off in the wetter regions of Malaysia but probably about one-tenth may be a better average estimate. Perhaps we should qualify such estimates with two cautionary notes: firstly, surface run-off should not be neglected in estimating the water balance; secondly, its attendant problems of soil water deficit and erosion are aggravated by clearing and, on sloping land, the combined effects of which may be very serious unless ameliorated by control measures.

EVAPORATION AND TRANSPIRATION

Evaporation is the conversion of liquids, water in this case, into vapour. The amount of water vapour air can carry at any temperature is limited and this increases with temperature. Air is saturated when it contains the maximum quantity of moisture it can hold stably (occasionally more is held unstably in 'super-saturated air'). The ratio of water actually present to the total required to saturate the air at the ambient temperature is called the relative humidity, usually expressed as a percentage. The difference between the amount of water in the air and that required to saturate it at a given temperature, expressed in terms of barometric pressure, is called the saturation deficit.

A land plant, by exposing tissues to the air to obtain carbon dioxide for photosynthesis, loses water vapour if the ambient air is not saturated. This is called transpiration and is a form of evaporation. The loss of water from a continuous cover of vegetation has been shown to be of the same order as from a free water surface, such as a lake. Water evaporates from soil surfaces at a rate which depends on the characteristics of the soil and its surface. The vaporisation of water requires the absorption of latent energy—about 580 calories per gram under average Malaysian lowland conditions—that is, nearly six times the amount of heat required to raise the same amount of water from freezing to boiling point without any change of state. Therefore energy is the first essential for evaporation to take place. Various meteorological conditions, such as the saturation deficit of the air and wind speed, modify the potential evaporation.

Various formulae devised to estimate the potential evaporation from meteorological observations are reviewed by PENMAN (1963) whose equation is used later in this discussion, the actual calculations following MCCULLOCH (1965). Essentially the Penman

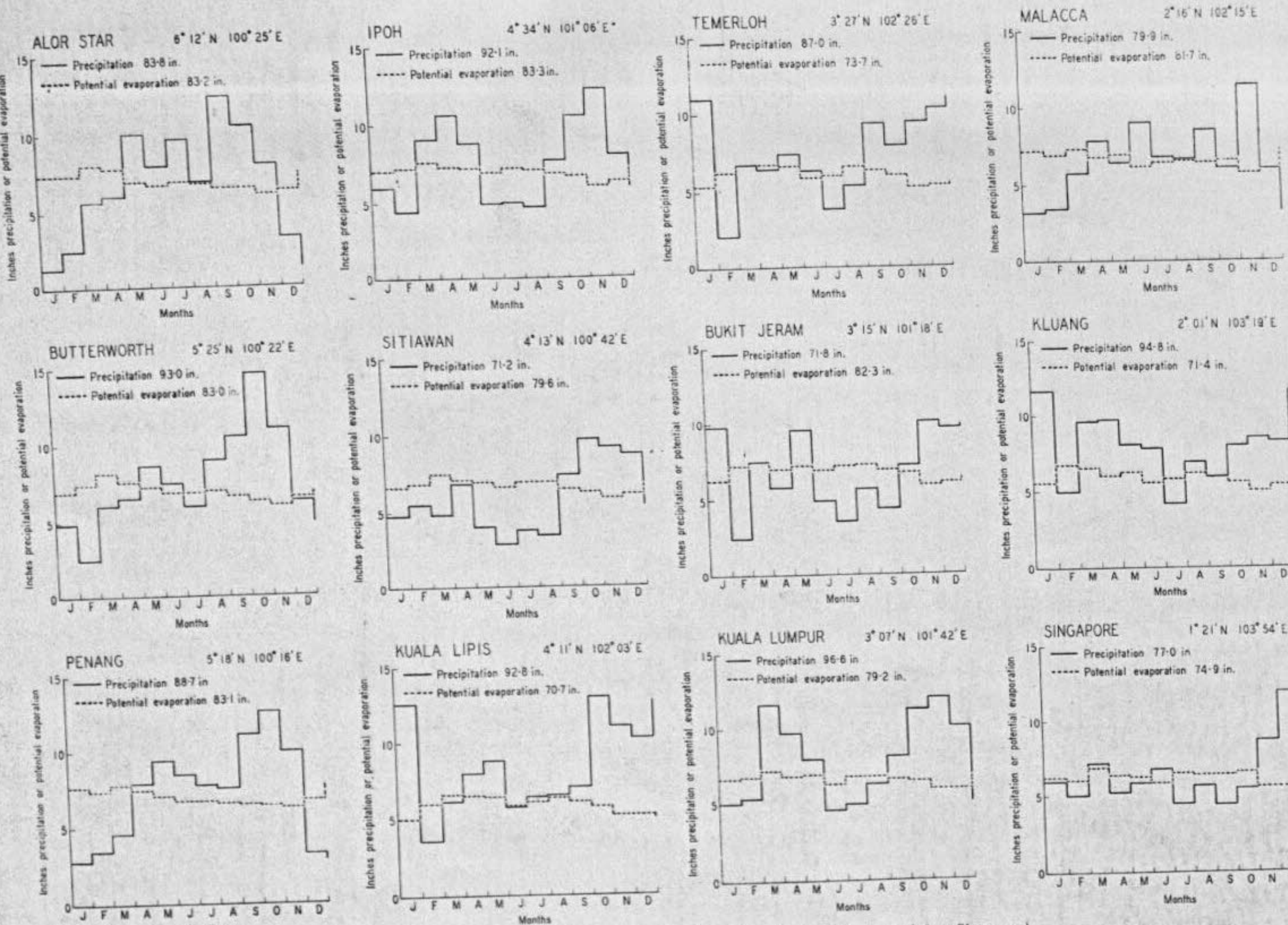

Figure 5A. Precipitation and Potential Evaporation (Alor Star to Kuala Lipis, Temerloh to Singapore)

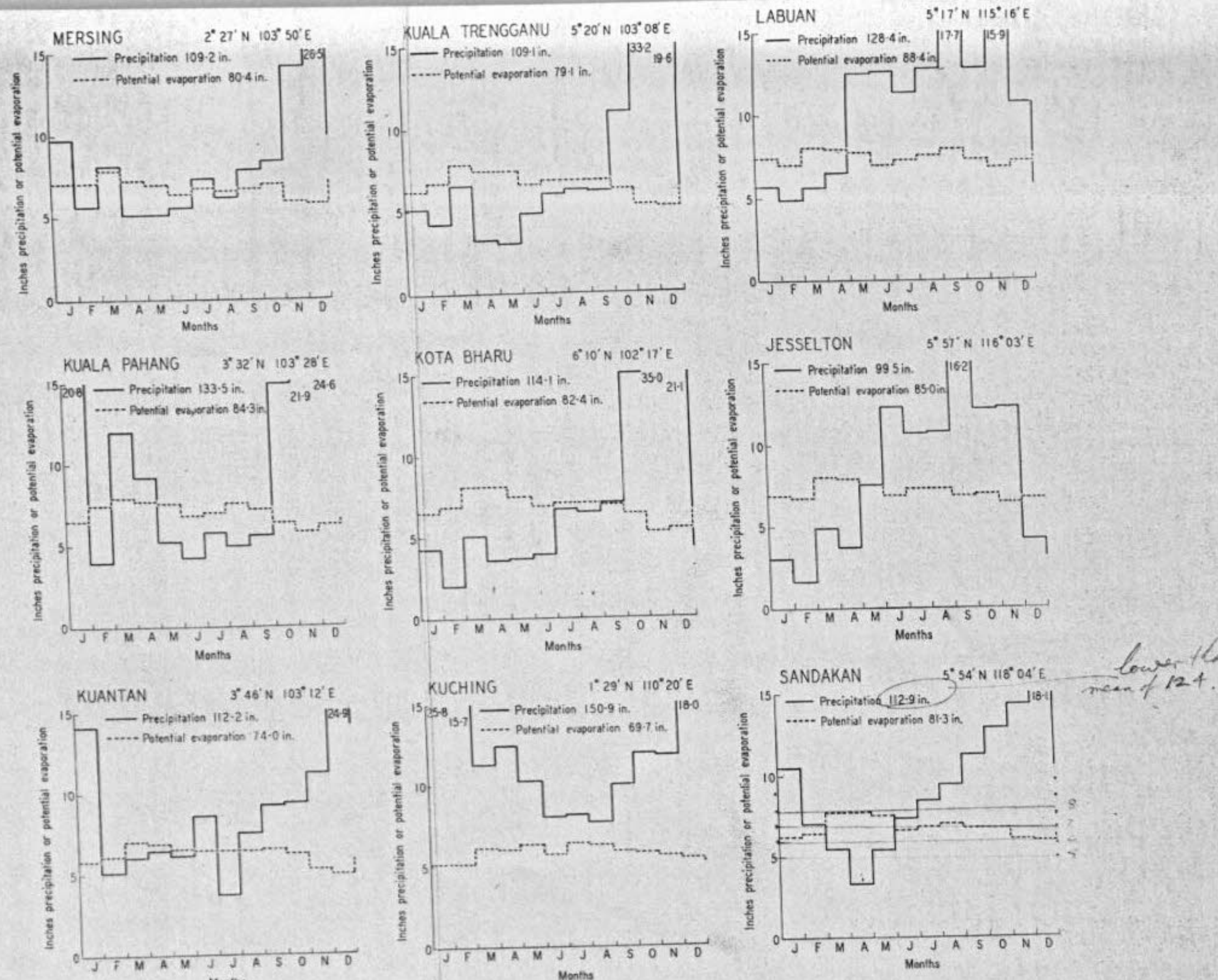

Figure 5B. Precipitation and Potential Evaporation (Mersing to Kuching, Labuan to Sandakan) equation estimates the evaporation from an extensive body of open water by calculating the incoming solar radiation, deducting the proportion lost by reflection and reverse heat radiation, and modifying with an atmospheric aerodynamic term. This estimate can be corrected by a factor for the type of vegetation and degree of ground cover to obtain a closer approximation of water requirements to meet losses by transpiration.

Careful distinction should be made between *potential* evaporation from open water (estimated after PENMAN and MCCULLOCH), which is regarded here as a measure of the transpiration stress imposed upon the plant by the environment, and *actual* evaporation whether from pans of various design (water not limiting) or from plants or soil when the availability of water will be a limiting factor. Estimates of potential evaporation may exceed actual evaporation and in many arid areas actual evaporation from pans exceeds by many times the total water available from precipitation or irrigation.

Some observations of evaporation from pans have been made in Malaya by the Meteorological Service and the Drainage and Irrigation Department. These, and evaporation losses from reservoirs, have been closely correlated with calculated saturation deficit and actual hours of bright sunshine by NIEUWOLT (1965), who has prepared maps of estimated monthly evaporation in Malaya by extrapolation from this material. Nieuwolt shows a range in mean monthly evaporation for various places from 4.25 to 6.5 inches, individual values ranging from more than 3.5 to less than 8 inches; he concludes that evaporation declines with distance from the coast and with elevation. Nieuwolt also plotted water balances for several stations and showed that although there was not a net annual deficit in precipitation compared with evaporation losses at any station, temporary deficits occurred during periods of up to six months' duration.

The potential evaporation calculated after Penman and McCulloch for each month of five years from the meteorological records of twenty-one stations in Malaysia (JOHN, 1958; KELLIHER, 1936; MATHER, 1959-62; STEWART, 1932, 1934, 1935, 1937) is plotted with the mean precipitation during the same periods in *Figure 5A* and *5B*. These calculated values are higher than the observed records and the figures given by Nieuwolt, considerably so over the lower range but only slightly so where evaporation is high and water stress is most critical. The discrepancy in the low range could be due to error in evaporation measurement (various types of pan are in use and they do not give exactly similar results), although reservoirs should give reliable figures. Alternatively the radiant energy may be over-estimated from the hours of bright sunshine recorded by Campbell-Stokes instruments or the atmospheric term in the Penman equation may not allow adequately for small saturation deficits in the humid tropics. However, although the differences cannot be explained, the calculated potential evaporation figures are used here as a measure of the transpiration stress of the environment, in view of the wide acceptance of Penman's concepts and the greater safety of using over-estimates rather than under-estimates.

VARIATION OF POTENTIAL EVAPORATION

The calculations support Nieuwolt's conclusion that evaporation declines with distance from the coast in the Malayan lowlands. The mean monthly potential evaporation falls an average of about one-tenth of an inch for each ten miles inland. The range in individual monthly values is from 4.4 to 9.2 inches, in monthly Means (five years) from 4.9 to 8.1 inches and mean annual totals from 69.7 to 88.4 inches. Since rain-bearing clouds may obscure the sun, and rain will reduce the atmospheric saturation deficit, an inverse correlation between potential evaporation and precipitation may be expected. Such a relationship has been established with statistical significance for most of the stations examined. For each station the potential evaporation which balances the precipitation has been calculated, the values obtained ranging from 6.1 to 7.5 inches per month, with an overall average of 6.7 inches. In each case this value is close to the mean potential evaporation for the station.

At stations where the annual potential evaporation exceeds the precipitation, it is critical) select the correct planting season, when there is a good chance of the rainfall exceeding ie mean potential evaporation (which shows less variation from year to year than preci- itation). Of the stations examined, rain would appear to be continuously in excess only t Kuching. At all other stations there are periods of apparent surplus or deficit in the ater balance. The favourable annual balance at strongly monsoon-type stations is decep- ve in that much of the rain falling during the wet season will run off and cannot add to ie soil water reserves.

Although actual or probable rainfall can be defined accurately, there are too many nknowns such as run-off, soil water storage capacity and the best estimate of evaporation to se. Hence no attempt is made here to draw up soil water 'balance sheets'. A young plant as a limited root system and water may not travel far through the soil when the moisture nmediately about it is exhausted, yet the leaves put out will transpire according to the nvironmental conditions. Therefore when planting rubber as stumps or plants in cores, igs or baskets, it is advisable to choose a season when enough rain may be expected to alance evaporation and to allow for some run-off. Eight inches per month may be taken s an approximate estimate. Experience suggests this is in the right order. Probably ore hardy forms of planting materials, such as legumes sown as dry, unsoaked seed, could e planted successfully when only 4 inches per month is expected. EDGAR (1960) comments iat legumes should be planted somewhat earlier than rubber, during the lighter rains, so iat the seeds are not washed away. On the other hand, rain in excess of 16 inches is likely) introduce problems of excessive run-off in any kind of planting.

RAIN INTERFERENCE

leavy rain falling during the usual working hours of daylight makes field work unpleasant, ifficult or impracticable. Harvesting latex from *Hevea* rubber trees is peculiarly susceptible) rain interference. Rain water running down the trunk of the tree may cause the tapping ıt to spill its latex, or, the flow of rain and latex along the channel and spout into the cup ıay cause the latter to overflow and lose the crop. This may apply either to the main arvest, usually collected before noon, or to the 'late drip' after normal collection time. ach combination of tapping system and variety of *Hevea* has a characteristic ratio of main arvest to late drip; those which produce a large proportion of late drip are more prone to ›se this by rain under current methods of crop collection. Spontaneous precoagulation long the cut, reducing latex flow and yield or subsequently forming lump in the cup, occurs ıore frequently after rain, especially if the trees are still wet. This appears to be due to estabilisation of the latex by substances extracted from the bark (COOK AND MCMULLEN, 951).

In a field of mature trees, conventionally spaced, the canopy covers virtually the whole ırea and the rain is intercepted by the foliage. A very small amount may be absorbed lirectly by the plant tissues; considerably more will be retained as surface moisture. When he surfaces are saturated, a continuous drip from the leaves and drain down the branches ınd trunk begin. Water may continue to trickle down the trunk for many hours after heavy rain and thus prevent tapping at the usual time.

The manner in which rain can interfere with tapping may be classified as follows and related to the time of day when the rain falls.

(a) When rain falls before tapping, the trees are wet and water trickles down the trunk, so that tapping must be postponed ('Late Tapping').

(b) When rain falls during tapping it is sometimes possible to collect some of the latex early, if the approach of rain is detected in time, this is 'Early Collection', or the rain may fall so rapidly and heavily that the latex is washed out of the cups ('Wash-Out').

(c) Rain after tapping may cause the loss of the late drip.

(d) Very heavy rain before normal tapping time may result in the trees being too wet to be tapped at all, or rain during the tapping period may also result in a 'Tapping Day Lost due to Rain'.

Together these amount to 'Total Rain Interference'.

The period before the trees may be tapped after rain varies with the rate of flow down the trunk and how soon the trees dry out. In this there is clonal variation, and the planting system also has an influence by modifying the amount of leaf in the canopy and the degree of exposure of the trunk to sun and wind. In areas where rain interference is likely, it may be possible to reduce the risks by appropriate choice of clone and planting distance but, so far, this aspect has not been studied sufficiently for any firm recommendations to be made.

If there are 120 trees per acre forming a continuous canopy, each tree will intercept 150 pints of water if one-tenth of an inch falls; only a small fraction of this would fill a 20-ounce cup. Therefore what is surprising is not that rain interference occurs, but that it is in general less than expectancy calculated from the number of rainy days—100 to 200 per year in Malaysia. A survey of seventy estates in Malaya over a five-year period (WYCHERLEY, 1963a) gave a Mean of only 5.3% of possible tapping days lost due to rain and 15.8% (including the 5.3%) in which rain interfered at all. The ranges were 0.9 to 14.8% and 6.6 to 29.2% respectively.

DIURNAL DISTRIBUTION OF RAINFALL

The explanation of the relatively low interference of rain with tapping lies mainly in the diurnal distribution of rainfall. Precipitation over five years at 17 lowland stations and 2 hill stations in Malaya, and at 3 stations each in Sabah and Sarawak, has been tabulated according to the time of day when it fell. The day is considered in four six-hour periods: from midnight until 6 a.m. (0 to 6 hours), from 6 a.m. until noon (6 to 12 hours which is the usual period for tapping operations), noon until 6 p.m. (12 to 18 hours) and from 6 p.m. until midnight (18 to 24 hours). At the 17 lowland stations, whose mean annual rainfall was 95.6 inches (five years' average), 21% of the rain fell from midnight until 6 a.m., 16% during the tapping period of 6 a.m. to noon, 35% from noon until 6 p.m. and 28% during the remainder until midnight. Thus the least rain fell during the tapping period itself, while the most rain fell during the afternoon allowing the maximum period for the trees to dry off before tapping the next day.

In Malaya the proportion of rain falling between midnight and noon declines highly significantly with distance from the coast; the large amount of afternoon and evening rain inland is undoubtedly related to the preponderance of instability rain, especially in the post-equinoctial periods of higher rainfall. This is illustrated in *Figure 6* and accords well with the general pattern of rain interference with tapping reported on the west coast of Malaya (WYCHERLEY, 1963a). Late Tapping was most common near the west coast and only occasional futher inland, Early Collection was fairly frequent both on the coast and inland and Wash-Outs were almost exclusively inland, among the estate records examined.

At first sight, the proportions of rain falling at different times of the day (expressed below as a percentage of the total anticipated rainfall in 24 hours) seem less favourable for latex harvest in Sabah and Sarawak than in Malaya:

Area	Proportions of rainfall over the 24-hour period of the day (%)			
	Hours			
	0—6	6—12	12—18	18—24
Sabah	27	15	20	38
Sarawak	34	17	25	24
Malaya	21	16	35	28

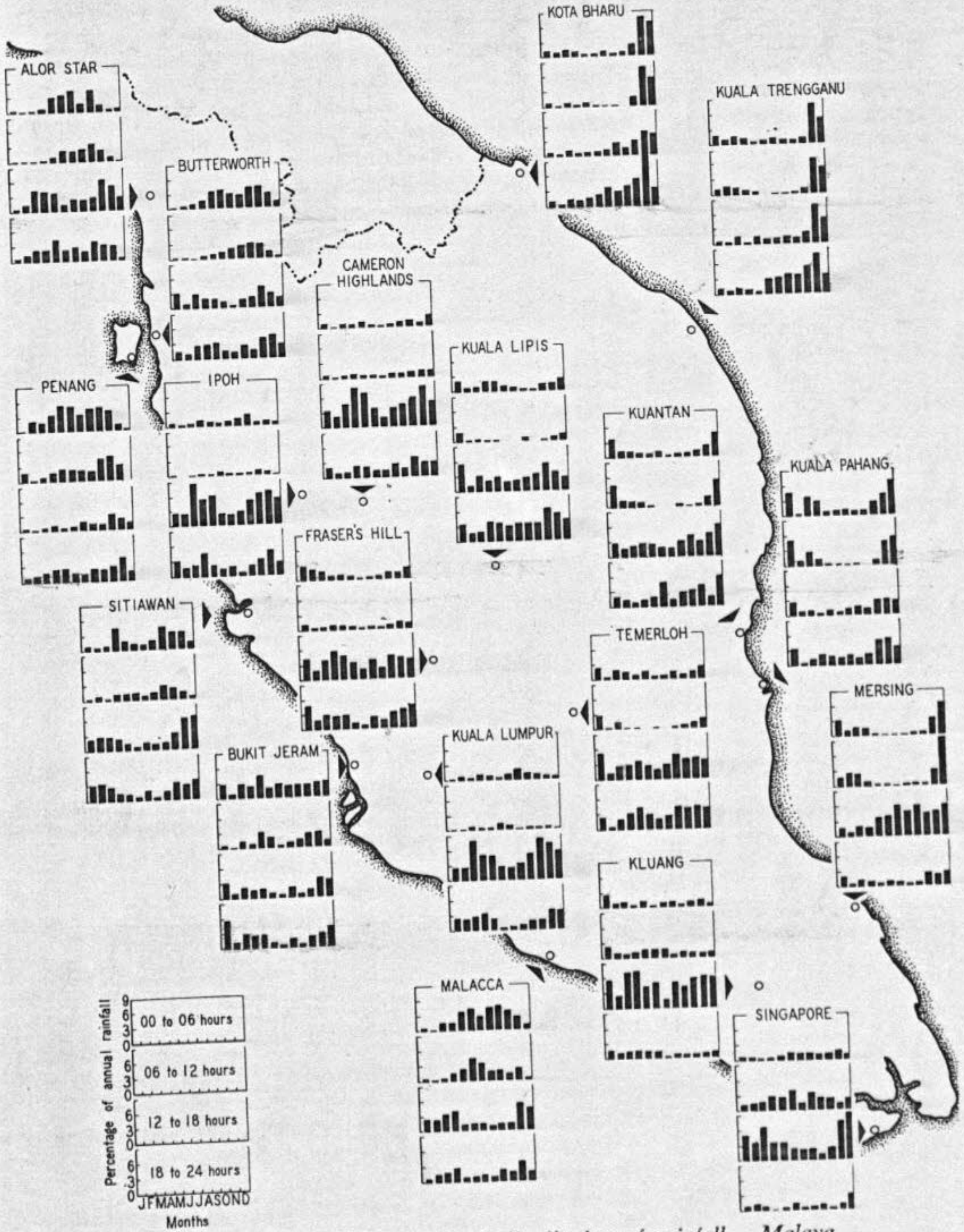

Figure 6. Diurnal and seasonal distribution of rainfall — Malaya

Moreover the rainfall is particularly heavy in Sarawak. However, all the stations considered in Borneo are coastal and further inland the balance may be more favourable, as in the Malayan lowlands. On the West Coast of Malaya much of the night and morning rain is brought by squalls across the Straits of Malacca and occurs throughout most of the year. On the East Coast of Malaya such rain, which may interfere with tapping, is concentrated during the North East Monsoon period and few tapping days are lost during the remainder of the year. The latter situation probably obtains at Kuching (although the high rainfall must be taken into account) and perhaps at Jesselton also, except that the rain falls during the South West Monsoon in this case. The other stations in Borneo probably suffer rather severe rain interference throughout the year (*Figure 7*).

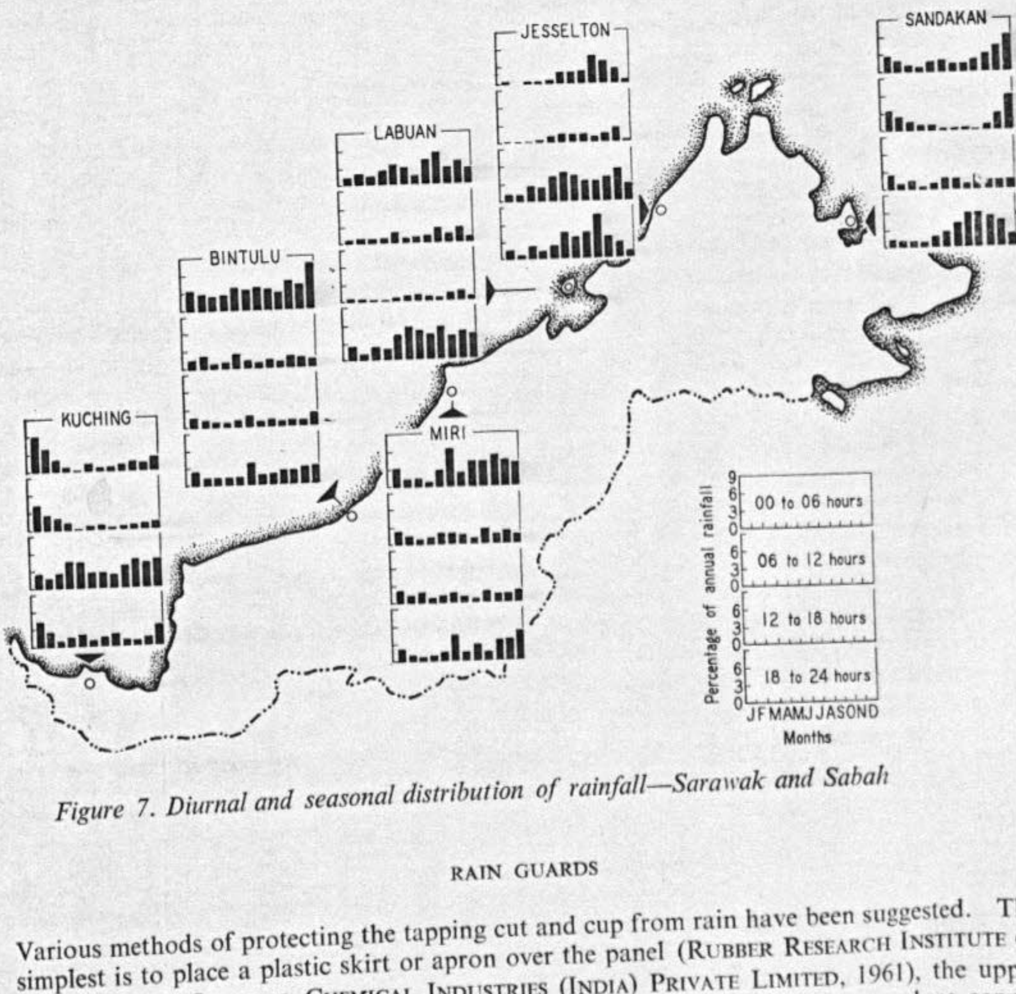

Figure 7. Diurnal and seasonal distribution of rainfall—Sarawak and Sabah

RAIN GUARDS

Various methods of protecting the tapping cut and cup from rain have been suggested. The simplest is to place a plastic skirt or apron over the panel (Rubber Research Institute of Ceylon, 1960; Imperial Chemical Industries (India) Private Limited, 1961), the upper edge being sealed to the tree by a suitable compound. Such an apron may reduce copper contamination of the latex in areas where copper fungicides are applied to the foliage or branches, but whether diseases are reduced by keeping the panel dry or increased by providing conditions conducive to their incubation is a matter of dispute; the efficacy of routine applications of fungicides to the panel during the wet season may be increased. The main disadvantage is that the apron interferes with the tapper's work on normal tapping days and this loss in efficiency will be outweighed by extra crop only in areas of severe rain interference.

Moulded rubber or plastic gutters fixed above the panel to throw clear water streaming down the trunk (SHELL COMPANY OF CEYLON LIMITED, 1959; RUBBER RESEARCH INSTITUTE OF CEYLON, 1960) must—like the aprons—be very effectively sealed onto the tree despite irregularities in the trunk circumference and the deteriorating effects of time. These are usually rather expensive guards to construct and fix; hence, only a high incidence of rain interference would justify their use. A lid to the cup may be necessary to prevent rain beating in directly.

One of the simplest methods is the 'abandonded cut' (TAPPAN, 1964). A new slightly shorter cut is opened below the old cut, which is abandoned after careful trimming, although a spout is left at its end to throw the water clear. A lid of tarpaulin or similar material, hinged to the tree, covers the spout and cup. There is not much experience of this or the other methods in Malaysia and any assessment of their likely value should note that rain guards do not protect the tappers, who are naturally discouraged from outdoor work during heavy rain.

CONCLUSIONS

The pattern of rainfall in Malaysia and some hydrological principles of interest to planters have been discussed. The information in this Manual is prepared to assess the probability of adequate or excessive rainfall for planting or harvesting operations during seasons or times of the day.

The data may be used for non-agricultural purposes such as the selection of suitable dates and times for outdoor sports or public events. No definite instructions are attempted but it is hoped that the information presented here will assist planters in Malaysia.

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