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Statistical Analysis of Rainfall Records at the R.R.I.M. Experiment Station

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Rainfall records relating mainly to the R.R.I.M. Experiment Station at Sungei Buloh in Selangor have been examined for their daily, monthly and annual variations. No significant trend in annual rainfall has been detected over long periods and sequences of wet and dry years have been found to agree closely with those predicted by the statistical theory of runs. Records of about 40 years constitute the minimum for the estimation of monthly Means (with an accuracy of ± 15%), while records of about 20 years are considered adequate for an accuracy of ± 10% in estimating the Mean number of rainy days. Annual figures have been more precisely estimated. Wet and dry months show a marked seasonal pattern. Confidence limits of the expected monthly and annual rainfall and the number of rainy days in a month have been derived. Monthly rainfall and the number of rainy days in a month have been found to be closely inter-related. The pattern of dry spells shows some seasonal variation.

Weather factors like rainfall, temperature and humidity are of great significance to agriculture. Rainfall especially is of primary importance for the establishment and growth of crops in the tropics. For perennial crops such as rubber, an assessment of the total annual rainfall and its distribution throughout the year are desirable. Planting of rubber seedlings (or buddings) is best confined to periods in which there is a good expectation of plentiful rain. Hence, the planting season in West Malaysia has been restricted usually to September and October, though April is also sometimes useful (WYCHERLEY, 1966). An examination of the rainfall records at the Experiment Station of the Rubber Research Institute of Malaya in Sungei Buloh (Selangor State) has been made to study primarily the daily, monthly and annual variations in rainfall in relation to rubber growing needs. Records of other stations have also been examined as supplementary data.

The following records were examined in this study:

(a) *R.R.I.M. Experiment Station*—Daily rainfall from 1947 to 1964; monthly rainfall from 1930 to 1937, 1940 and 1947 to 1964; annual rainfall from 1930 to 1940 and 1947 to 1964; and the total rainfall from January to October 1941. The annual rainfall for 1941 was estimated on the basis of the 10-month total, by applying a conversion factor based on the records of previous years.

(b) *For other stations*—Hydrological data, rainfall records, 1879 to 1958; and Rainfall statistics of the British Borneo Territories, 1896 to 1957.

In all cases, precipitation has been observed daily at about 7.30 in the morning and the rainfall recorded for any day refers to the previous 24 hours.

METHODS

1. Trends in Annual Rainfall

Use of past records to predict the probability of rainfall occurrence or patterns in the rainfall distribution is based on the assumption that there is no significant long-term trend. It was hence decided to test whether the observed annual rainfall values subscribed to any specific pattern. Since the rainfall data at the Experiment Station were available only for some 30 years, records of 15 other stations in different rainfall regions (DALE, 1959; WYCHERLEY, 1963a and b) and with varying incidences in

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rainfall—were studied (*Table 1*). Linear trends were fitted for each station and it was found that the trend, as reflected in the regression coefficient, was statistically significant at only one station, i.e. Kangar Hospital. A possible explanation for this may be the very low rainfall during 1956–1958. Annual rainfalls of four representative stations including Sungei Buloh were plotted against the years; the lines for Mean annual rainfalls were super-imposed for comparison with the linear trends fitted (*Figure 1*). Over the limited period for which data were available, the observed annual rainfall records at the Experiment Station showed no definite trend.

2. *Sequences of Wet and Dry Years*

The extent of succession of wet and dry years was examined. Since rainfall records of Sungei Buloh were too limited and discontinuous to enable this study, those of Tanglin Hospital (1879–1940), which is in the same rainfall region and is the station nearest to Sungei Buloh, were used. A wet year was defined in the study as that with a rainfall greater than the upper (designated x_w) and a dry year was defined as that with a rainfall less than the lower (designated x_d), of the 99% confidence limits of the true Mean annual rainfall at Tanglin Hospital; a normal year thus had a rainfall between these limits.

The distribution pattern of the annual rainfall values at Tanglin Hospital was found to be approximately normal and hence the chance of any year's annual rainfall falling below x_d (or being above x_w) was found to be 0.37 only. Substituting this ($p=0.37$) in Equation (1) in the *Appendix*, it is seen that runs of two wet (or dry) years can be expected only once in a decade (or 6 times in the 62 years studied); runs of three wet (or dry) years could be expected only once every 30 years (or twice in the 62 years). To compare these calculated mean recurrence intervals with the observed data, each annual rainfall figure was classified: *D*, *W* or *N* according as it was $\leq x_d (=87.15$ in.), $\geq x_w (=96.69$ in.) or between x_d and x_w respectively (*Table 2*). The annual rainfall for 1898 was not available and therefore, for classification purposes, the year was assumed to be

TABLE 1. LINEAR TRENDS FOR ANNUAL RAINFALL (y), WITH YEARS (x) AT DIFFERENT STATIONS

Station	Period	No. of years	Mean annual rainfall (in.)	Linear trend†	Equation fitted
R.R.I.M. Experiment Station, Sungei Buloh	1930–1964	30	98.4	3.9 N.S.	$y= 97.7+0.039\ (x-1930)$
Tanglin Hospital, Kuala Lumpur	1879–1958	70	93.5	3.4 „	$y= 92.2+0.034\ (x-1879)$
Kuala Selangor Hospital	1887–1958	67	72.8	6.1 „	$y= 70.7+0.061\ (x-1887)$
Tapah Hospital	1889–1958	64	143.8	−12.0 „	$y=147.8-0.120\ (x-1889)$
Raub Hospital	1900–1958	54	87.9	− 1.1 „	$y= 88.2-0.011\ (x-1900)$
Pekan Hospital	1898–1957	50	126.4	− 8.0 „	$y=128.7-0.080\ (x-1898)$
Port Dickson Hospital	1891–1958	53	89.1	−10.8 „	$y= 92.9-0.108\ (x-1891)$
Jelebu Hospital	1891–1958	55	65.1	− 1.4 „	$y= 65.5-0.014\ (x-1891)$
Rengam Estate	1913–1958	41	100.7	4.2 „	$y= 99.8+0.042\ (x-1913)$
Ipoh Hospital	1892–1958	58	101.9	10.2 „	$y= 98.9+0.102\ (x-1892)$
Taiping Hospital	*1888–1958*	62	*166.0*	3.7 „	$y=164.7+0.037\ (x-1888)$
Kangar Hospital	1909–1958	50	79.9	−25.1*	$y= 86.0-0.251\ (x-1909)$
„ „ (omit 56–58)	1909–1955	47	80.7	−19.7 N.S.	$y= 85.2-0.197\ (x-1909)$
Kuching	1876–1961	75	157.6	−13.1 „	$y=163.2-0.131\ (x-1876)$
Jesselton Aerodrome	1889–1957	42	107.6	18.4 „	$y=100.8+0.184\ (x-1889)$
Sandakan	1879–1957	56	124.0	− 1.1 „	$y=124.4-0.011\ (x-1879)$
Keningau	1910–1961	40	68.1	−26.2 „	$y= 75.4-0.262\ (x-1910)$

*$P<0.05$ N.S.: Not significant †In cents/year, 100 cents=1 in.

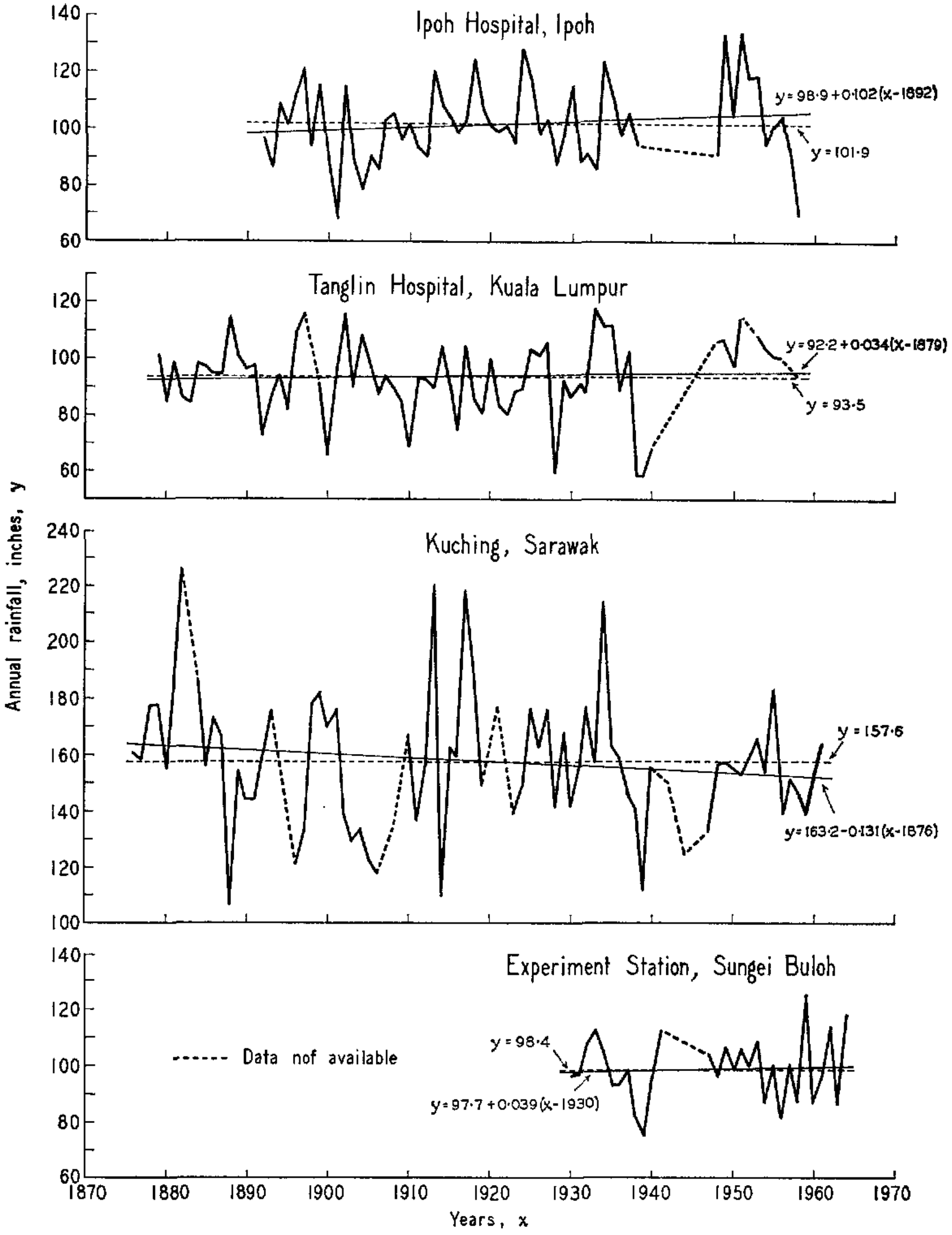

Figure 1. Trends in the annual rainfall at four stations.

normal. *Table 2* shows that there had been six runs of 2 and two runs of 3 'wet' years and five runs of 2 and one run of 3 'dry' years—these agree well with the calculated values.

TABLE 2: SEQUENCES OF WET AND DRY YEARS AT TANGLIN HOSPITAL, KUALA LUMPUR

Year	Rainfall (in.)	Classification	Year	Rainfall (in.)	Classification
1879	101.13	W	1910	68.63	D
1880	84.47	D	1911	93.79	N
1881	99.59	W	1912	92.83	N
1882	86.18	D	1913	89.18	N
1883	84.82	D	1914	104.44	W
1884	98.62	W	1915	89.70	N
1885	97.86	W	1916	74.34	D
1886	94.86	N	1917	104.78	W
1887	94.43	N	1918	84.48	D
1888	115.76	W	1919	80.20	D
1889	100.93	W	1920	100.20	W
1890	96.59	N	1921	83.06	D
1891	98.02	W	1922	80.58	D
1892	72.43	D	1923	88.01	N
1893	87.67	N	1924	89.57	N
1894	94.32	N	1925	103.76	W
1895	82.24	D	1926	101.52	W
1896	109.01	W	1927	106.16	W
1897	116.28	W	1928	59.33	D
1898	N.A.	N	1929	92.90	N
1899	91.45	N	1930	87.04	D
1900	65.49	D	1931	91.46	N
1901	95.05	N	1932	87.92	N
1902	116.40	W	1933	118.14	W
1903	89.89	N	1934	111.63	W
1904	108.01	W	1935	111.89	W
1905	98.96	W	1936	88.18	N
1906	87.74	N	1937	102.81	W
1907	93.77	N	1938	58.93	D
1908	89.29	N	1939	58.28	D
1909	84.35	D	1940	68.03	D

D=Dry condition, F=Wet condition
N=Normal condition N.A.=Not available
$\bar{x}$ =91.92 inches, s.d.=14.02 inches
99% confidence limits for the true mean is $87.15 \leq a \leq 96.69$
$P(x \leq 87.15) = P(x \geq 96.69) = p = 0.37$ (from normal distribution)

From observed data:

		Frequency	Recurrence interval
Consecutive	2 years W	6	62/6=10.3 years
,,	2 years D	5	62/5=12.4 years
,,	3 years W	2	62/2=31.0 years
,,	3 years D	1	62/1=62 years

3. Monthly and Annual Variations in Rainfall

Having established that the annual rainfall data at the Experiment Station do not subscribe to any trend, their variations have been studied in greater detail. *Figure 2* shows the cumulative monthly rainfall obtaining for the two periods: 1930 to 1940 (except 1938 and 1939) and 1947 to 1964. The graphs follow the same pattern for the 1930–1940 as well as for 1947–1964 periods, except for the months April to November, during which rainfall during 1947 to 1964 has been the highest. But the Means of the different months for the two periods, as compared on the basis of their respective standard deviations, are not significantly different. Hence, the two sets of data have been pooled to give 27 years of monthly and annual data. The Means, standard deviations (s.d.) and the corresponding coefficients of variation (c.v.$=100\frac{\text{s.d.}}{\text{mean}}$) of the 27 years of record are shown in *Figure 3*. The Mean monthly values for 27 years show that the rainfall increases from about 7 in. in January to about 11 in. in April and then decreases for the next two months (*Table 3*). The rainfall is lowest in June (4.6 in.) and it then increases till November (11.5 in.) after which there is a slight drop (December 10.2 in.). The standard deviations (s.d.) also follow a similar pattern,

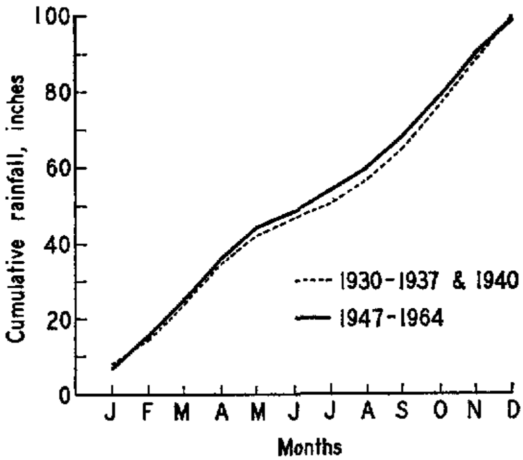

Figure 2. Cumulative monthly rainfall at Sungei Buloh.

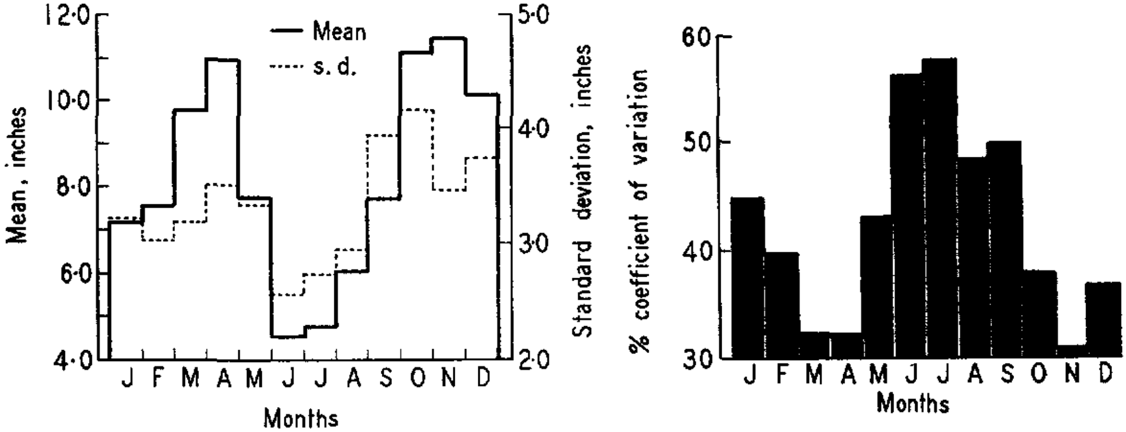

Figure 3. Means, standard deviations and coefficients of variation (%) of monthly rainfall at Sungei Buloh.

varying with the Mean. On the other hand, the coefficients of variation (c.v.) are low for the wet months (October–December and March–April) and higher for the dry months (June–July). This is the pattern usually expected. The Mean annual rainfall is of the order of 100 in. while the corresponding c.v. is about 10 percent.

To determine whether the distribution of the individual months and years around the Means follow a symmetrical or skew pattern, the number of occasions with rainfall occurring below, above and equal to the Means for the different months has been given (*Table 3*). It would be observed that of the 27 values corresponding to the 27 years for each of the months

TABLE 3. DATA OF MONTHLY AND ANNUAL RAINFALL AT SUNGEI BULOH

Month	1930–'64 except '38 & '39				Number of occasions with rainfall			No. of years record for given d	
	Mean	Median	s.d.	c.v. (%)	Above Means	Below Means	Equal to Means	d_1	d_2
January	**7.23**	**6.28**	3.25	44.95	**10**	**16**	1	16	26
February	7.62	7.76	3.03	39.76	15	12	–	13	21
March	9.75	9.32	3.18	32.62	13	14	–	9	15
April	11.00	11.12	3.55	32.27	14	13	–	9	15
May	7.81	7.80	3.38	43.28	13	14	–	15	24
June	4.55	4.39	2.57	56.48	13	14	–	24	40
July	4.78	4.58	2.76	57.74	**10**	**17**	–	24	42
August	**6.10**	**5.22**	2.96	48.52	**9**	**18**	–	18	30
September	**7.83**	**6.95**	3.92	50.06	12	15	–	19	32
October	11.17	11.12	4.25	38.05	13	14	–	12	19
November	11.47	11.40	3.53	30.78	13	14	–	8	13
December	10.18	10.47	3.76	36.94	14	13	–	11	18
Annual	99.49	99.34	10.13	10.18	12	15	–	13	19

Figures in bold show departures from symmetry.
For monthly, d_1 and d_2 correspond respectively to ±20 and ±15% of the Means.
For annual, d_1 and d_2 correspond respectively to ±5 and ±4% of the Mean.

TABLE 4(a). SEQUENCES OF WET AND DRY MONTHS AT SUNGEI BULOH

No. of months in sequence	Rainfall above 8.29* in.	Rainfall below 8.29 in.
3 months	18	9
4 ,,	6	8
5 ,,	3	4
6 ,,	–	2
7 ,,	–	2
8 ,,	–	2
Total	27	27

* Mean monthly rainfall over 27 years.

and annually, only in 3 cases (i.e. in January, July and August) the frequencies with rainfall above and below the Means are very different. For the remaining months and annually, the frequencies of occurrence of above and below the respective Means are nearly the same, suggesting a symmetrical distribution. As a further check, the Medians of the individual months' and annually have been tabulated along with the monthly Means. It is evident that the Mean and the Median are comparable except for January, August and September.

TABLE 4(b). DISTRIBUTION OF WET AND DRY SEQUENCES AT SUNGEI BULOH

Month	Rainfall above 8.29 in.	Rainfall below 8.29 in.	No sequences
January	7	8	12
February	7	8	12
March	10	6	11
April	10	5	12
May	5	12	10
June	—	18	9
July	—	20	7
August	1	19	7
September	7	13	7
October	15	4	8
November	17	3	7
December	14	5	8
Total	93	121	110
% of 324 months	28.7%	37.3%	34.0%

4. Sequences of Wet and Dry Months

As well recognised seasonal patterns are now involved, random factors are not so dominant in the month-to-month as in the year-to-year comparison, so months have been classified as wet or dry simply as the rainfall in the month exceeds or falls short of the Mean monthly rainfall of 8.29 in. over 27 years. *Table 4(a)* shows the number of occasions on which sequences of three or more consecutive months have experienced rainfall above or below 8.29 inches. *Table 4(b)* shows the distribution of these sequences over different months: one-third of the individual months is not in any sequence, about one-third is in dry sequences (representing dry seasons) and the remaining is in wet sequences (representing wet seasons). Wet seasons are at a maximum during October to December and minimum during June to August, while the reverse is the case for dry seasons. The 27 wet seasons had an average surplus rainfall of 12.51 in. above the average with a range of 4.29 to 23.29 in. The 27 dry seasons had an average deficit rainfall of 14.27 in. below the average with a range of 1.94 to 26.38 in.

The frequency with which the different months' rainfall exceeds 8.29 in. has been given in *Table 4(c)*. It will thus be seen that, for the 5 months (March, April, October to December), the probability is above 0.67 for rainfall exceeding the Mean monthly rainfall of 27 years.

TABLE 4(c). NUMBER OF YEARS IN WHICH MONTHLY RAINFALL EXCEEDS THE MEAN FOR 27 YEARS AT SUNGEI BULOH

Month	No. of years
January	8
February	8
March	18
April	20
May	11
June	2
July	3
August	5
September	11
October	19
November	23
December	18

Also, for the eighteen 3-month wet seasons, five began in February and October, three in March and September and two in November. Of the nine longer wet seasons, two began in February and the rest either in September or October. Seventeen of the dry seasons set in June.

5. Records for Accurate Estimation

The minimum number of years of record needed for estimating Mean rainfall is the number giving an estimate of the true value to within the degree of accuracy required. This number depends on the scatter characteristics of individual data.

It has been shown already that the monthly data at the Experiment Station for the 27 years follow approximately symmetrical distributions (except for January, July and August). Putting the accuracy required (d) as $\pm$ 20 and $\pm$ 15% of the Means for the estimation of the different monthly rainfall values, the minimum number of years of record required has been calculated from Equation (2) in the *Appendix* and tabulated (*Table 3*).

The minimum number of years of record required varies between 8 and 24 years for the different months when the accuracy required is $\pm$ 20% of the Means. When $d = \pm$ 15% of the Means, the number of years of record varies between 13 and 42 years for the different months.

For annual records, since the coefficient of variation is lower, it was thought best to derive the minimum record by putting $d = \pm 5$ and $\pm$ 4 % of the Mean. Even for *a* $\pm$ 4% accuracy the number of years of record required is only 19.

The different monthly rainfall Means based on 40 years' record will not differ from their true Means by more than $\pm$15% while, for the annual Mean based on the same length of record, the true Mean will be within $\pm$3%. DALE (1960) quotes the c.v. of annual rainfall for various parts of Malaya as lying between below 10% to over 22% and the c.v. of the different monthly rainfall varying between below 20% to over 80%. Using his upper limits, it can be seen that, while 40 years' records could be considered sufficient for the estimation of annual Mean within $\pm$7% of the Mean for all parts of Malaya, the same records used in estimating the different monthly Means would give only an accuracy of about $\pm$25%.

6. Confidence Limits for Rainfall Values

The different monthly and annual Means provide only point estimates and hence one would be more interested to have limits within which the expected rainfall for each of the months in the year can be confidently predicted. Apart from the three months—January, July and August—which showed slight skewness to the left, the other monthly and annual data can be considered as symmetrical and also as having been normally distributed. The 67 and 95% confidence limits for the expected monthly and annual rainfall values can be calculated from Equation (3) in the *Appendix*.

The confidence limits are shown in *Table 5* along with the observed lowest and highest values of the 27 years' record. These limits should be treated as 'rough guides' to the monthly and annual rainfall variations, firstly, because of the limitation in the length of data available and, secondly, because of the assumption of symmetry.

7. Variations in Rainy Days

Daily rainfall records are available for the 18-year period (1947–1964). A rainy day is defined here as the day in which the rainfall exceeds 0.01 in. *Table 6* shows the Means, standard deviations and the corresponding coefficients of variation of the number of rainy days in each of the months and over the year. It is seen that the Mean number of rainy days in a month, from March to April and October to December is around 20. The Mean number of rainy days is lowest for the months of June and July. The Median of the number of rainy days has also been calculated for each of the months and over the year to determine how far they differ from the corresponding Mean values. There is good agreement between the two estimates, suggesting symmetrical patterns for the distribution of rainy days in all cases. The standard deviation of the number of rainy days averages 3.5 over the months, ranging from 4.4 for May to 2.2 for

TABLE 5. CONFIDENCE LIMITS OF EXPECTED MONTHLY AND ANNUAL RAINFALL VALUES AT SUNGEI BULOH

Month	Observed		67% confidence limits		95% confidence limits	
	Lowest	Highest	Lower	Upper	Lower	Upper
January	2.02	14.18	4.08	10.38	0.86	13.60
February	0.76	15.64	4.68	10.56	1.68	13.56
March	4.86	19.17	6.67	12.83	3.52	15.98
April	5.57	18.75	7.56	14.44	4.04	17.96
May	3.03	14.59	4.53	11.09	1.19	14.43
June	0.87	12.30	2.06	7.04	0	9.59
July	0.66	11.38	2.10	7.46	0	10.19
August	1.80	13.51	3.23	8.97	0.30	11.90
September	2.42	18.34	4.03	11.63	0.15	15.51
October	3.39	20.89	7.05	15.29	2.84	19.50
November	3.72	18.99	8.05	14.89	4.55	18.39
December	3.35	18.12	6.53	13.83	2.81	17.55
Annual	80.18	125.74	89.66	109.32	79.64	119.34

September. The minimum number of years of record necessary for estimating the Mean number of rainy days for the various months are also tabulated in *Table 6*. It is seen that the number of years of record varies between 8 and 23 for the different months except for June (30 years). About 10 years' record would be sufficient for estimating the Mean number of rainy days in a year to within ± 5% of the Mean. The 67 and 95% confidence limits within which the expected number of rainy days will lie for each of the months and annually are also given in *Table 6*.

8. *Daily Rainfall–Frequency Relations*

Frequency distributions of the observed daily rainfall records for the years 1947 to 1964 have been made for each month. These distri-

TABLE 6. DATA OF THE NUMBER OF RAINY DAYS AT SUNGEI BULOH

Month	Mean	Median	s.d.	c.v. (%)	No. of years record for given *d*	67% confidence limits		95% confidence limits	
						Lower	Upper	Lower	Upper
January	14.8	14.5	3.7	25.00	19	11.2	18.4	7.5	22.1
February	14.2	14.5	3.6	25.35	19	10.7	17.7	7.1	21.3
March	18.3	18.5	3.5	19.13	12	14.9	21.7	11.4	25.2
April	18.9	19.0	3.4	18.00	11	15.6	22.2	12.2	25.6
May	16.2	16.0	4.4	27.16	22	11.9	20.5	7.6	24.8
June	10.3	11.0	3.3	32.03	30	7.1	13.5	3.8	16.8
July	11.7	12.0	3.3	28.20	23	8.5	14.9	5.2	18.2
August	14.1	14.0	3.0	21.28	14	11.2	17.0	8.2	20.0
September	14.7	15.0	2.2	14.97	8	12.6	16.8	10.4	19.0
October	19.6	20.0	3.7	18.88	12	16.0	23.2	12.3	26.9
November	20.6	21.5	3.5	16.99	10	17.2	24.0	13.7	27.5
December	18.2	17.5	4.0	21.98	15	14.3	22.1	10.4	26.0
Annual	191.4	189.5	14.6	7.63	8	177.2	205.6	162.8	220.0

$d = \pm 10\%$ of the Means for monthly and $\pm 5\%$ of the Mean for annual.

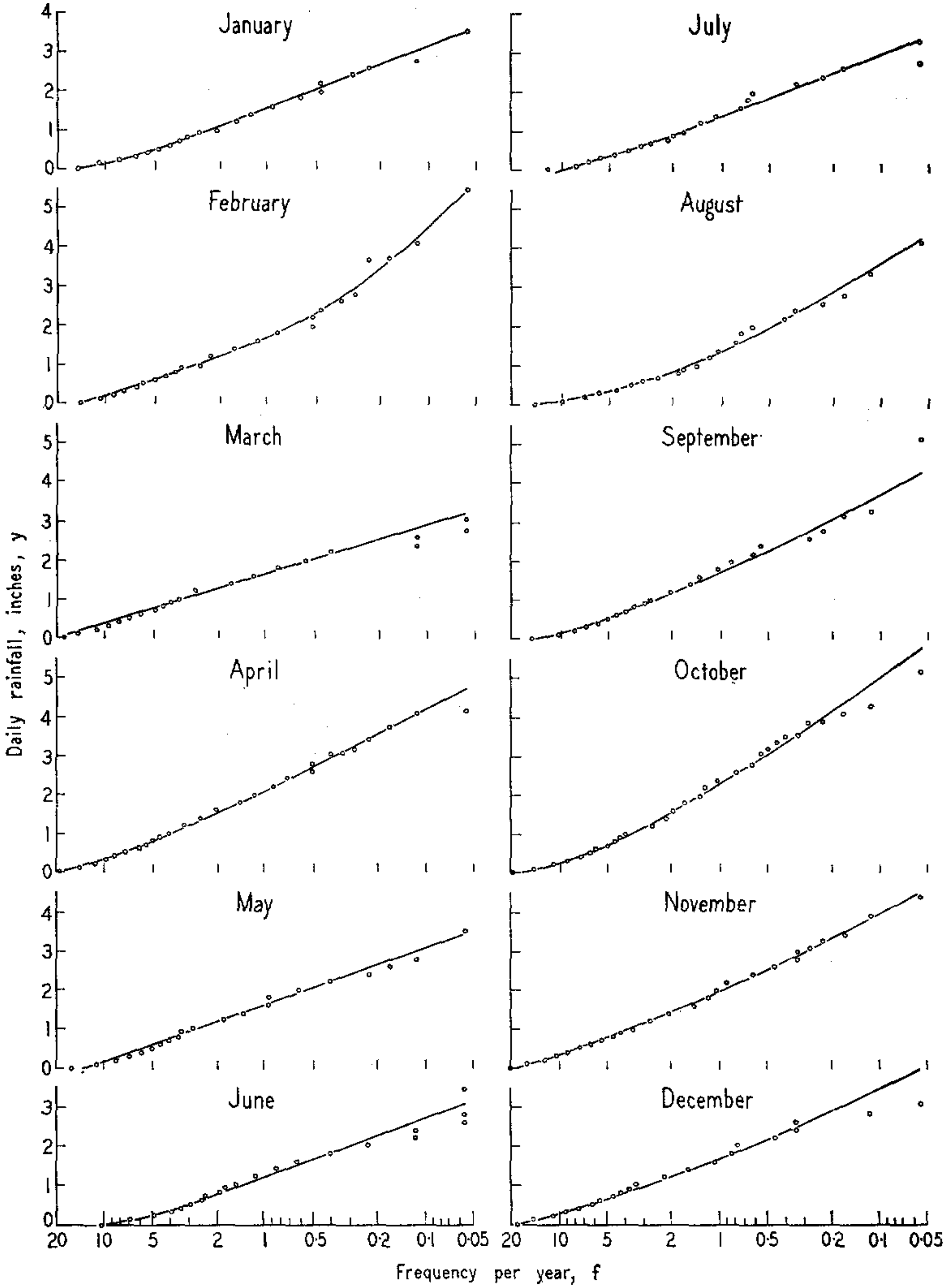

Figure 4. Daily rainfall–frequency relationships for the different months at Sungei Buloh.

TABLE 7. EXPECTED FREQUENCY OF OCCURRENCE EXCEEDING VARIOUS RAINFALL MAGNITUDES AT SUNGEI BULOH

Daily rainfall magnitude	Frequency of occurrence (f)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.2″ & above	8.3	9.1	13.2	12.0	9.3	5.5	6.5	7.2	8.9	11.0	12.9	11.2
0.4″ & above	5.5	6.3	9.1	8.7	6.6	3.5	4.5	4.5	6.5	7.4	8.9	7.4
0.6″ & above	3.8	4.6	6.3	6.3	4.7	2.4	3.3	3.0	4.7	5.5	6.6	5.4
0.8″ & above	2.8	3.3	4.4	4.9	3.3	1.7	2.4	2.2	3.5	4.2	4.9	3.8
1″ & above	2.0	2.5	3.0	3.8	2.4	1.3	1.8	1.6	2.6	3.3	3.6	2.8
1.5″ & above	1.0	1.5	1.2	2.0	1.0	0.6	0.8	0.8	1.3	2.0	1.8	1.3
2.0″ & above	0.5	0.7	0.5	1.1	0.5	0.3	0.4	0.4	0.7	1.3	1.0	0.6

butions skew extremely to the left. It is possible to calculate from them the average number of days in each month on which the rainfall is likely to exceed a specified amount. This number is designated as the frequency of occurrence (f) of the specified daily rainfall in the month. Thus, if over 0.5 in. of rain fell in one day on 85 occasions in the month of January during the 18 years of available record, the frequency of occurrence (f) of 0.5 in. rainfall in January at Sungei Buloh is (85/18) 4.7.

TABLE 8(a). RELATIONSHIP BETWEEN THE MONTHLY RAINFALL (y) AND THE NUMBER OF RAINY DAYS (x) AT SUNGEI BULOH

Month	Relation $y=a+bx$	Correlation coefficient (r)
January	$y=-1.93+0.595x$	0.648**
February	$y=0.472+0.553x$	0.600**
March	$y=4.82+0.266x$	0.387 N.S.
April	$y=-0.263+0.624x$	0.609 **
May	$y=-2.48+0.637x$	0.776 ***
June	$y=-0.198+0.444x$	0.543 *
July	$y=0.177+0.451x$	0.517 *
August	$y=-0.018+0.410x$	0.458 ($P<0.10$)
September	$y=-3.42+0.762x$	0.369 N.S.
October	$y=0.055+0.570x$	0.485 *
November	$y=-2.81+0.687x$	0.578 *
December	$y=-1.14+0.573x$	0.737 ***
All months	$y=-1.62+0.621x$	0.700 ***

*** $P<0.001$; ** $P<0.01$; * $P<0.05$;
N.S.: Not significant.

Where log f is plotted against its specified daily rainfall (*Figure 4*), the relationship appears to be linear for some of the months (March, July and September) but curvilinear for the other months (Equation (4) in the *Appendix*). Smooth free hand curves have been drawn for such relationships and, from them, the expected frequencies of occurrence for each month of daily rainfall in excess of certain specified amounts have been estimated (*Table 7*).

TABLE 8(b). TEST OF HOMOGENEITY OF THE DIFFERENT MONTHLY SLOPES AND INTERCEPTS

(i) *Slopes* (b's)

Source	d.f.	Mean squares
Due to common b	1	746.7484
Due to different b's	12	65.1962
Differences among b's	11	3.2369 N.S.
Residual error	192	8.5357
Pooled error	203	8.2486

(ii) *Intercepts* (a's)

Source	d.f.	Mean squares
Differences among a's	11	12.5920 N.S.
Error (2)	203	8.2486
Error (1)	214	8.4718

9. Monthly Rainfall and Rainy Days

The relationship between the amount of rainfall and the number of rainy days in a month for each month during 18 years (1947–1964) has been found to be similar and linear (*Figure 5*). Linear regressions of monthly rainfall on the number of rainy days have been calculated for each of the months and these are listed in *Table 8(a)*. Differences among *b*'s (the slopes) and also the differences among *a*'s (the intercepts) are not significantly different for the different months, as can be seen in *Table 8(b)*. Thus, all the monthly data can be pooled and one linear relation can be derived between monthly rainfall and the number of rainy days in a month.

The general linear relationship which is highly significant is $y=0.621x-1.62$. The 95% confidence limits (approximate) for the scatter of points have also been shown in *Figure 5*. This relationship can be used to estimate the amount of rainfall expected in any month of the year for a given number of rainy days. The inverse relationship, estimating the number of rainy days from known monthly rainfall, is also of practical interest. The relationship derived could be used for this purpose as well. From the Equation, $y=a+bx$, $x=\frac{y^1-a}{b}$ where y^1 is a given value of y. It is possible to construct confidence limits for the predicted x, for a given value of y. The esti-

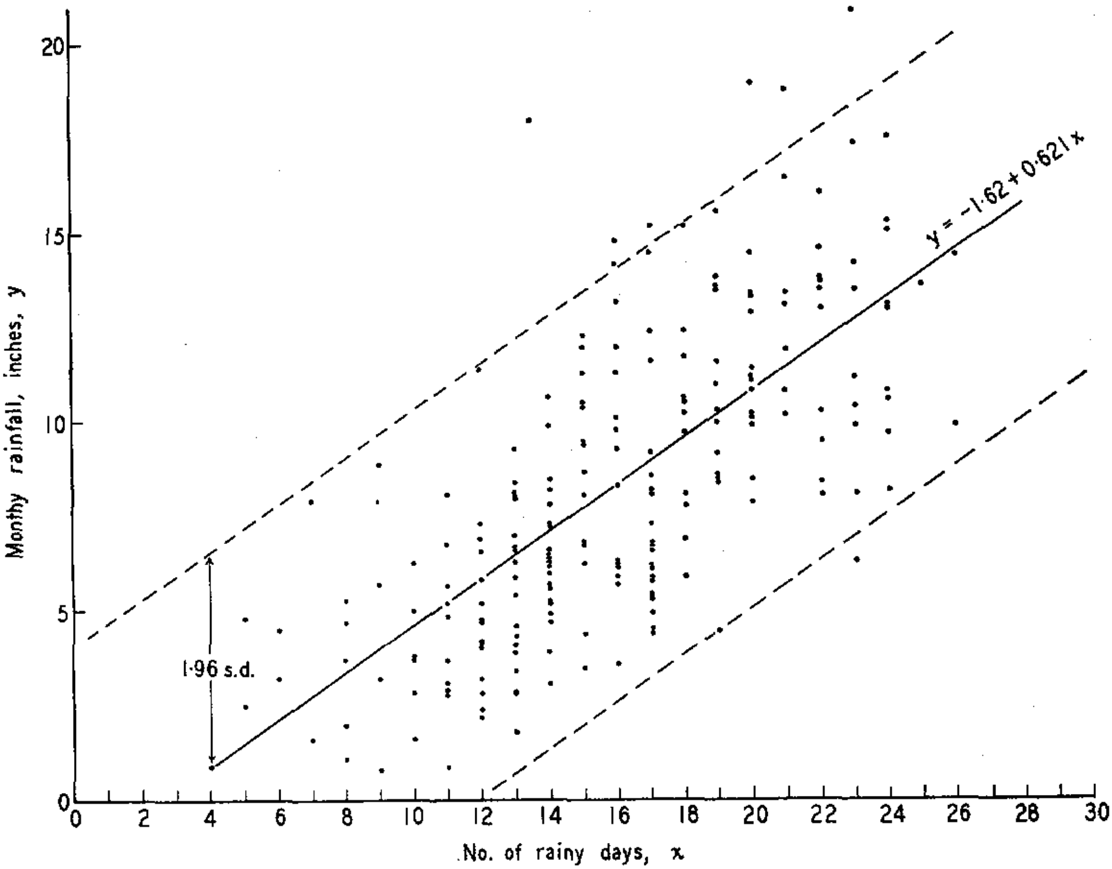

Figure 5. Relationship between the monthly rainfall and the number of rainy days in a month at Sungei Buloh.

mated number of rainy days for each of the months, derived from the general relationship for Mean monthly rainfall values, closely agree with the observed Mean number of rainy days.

10. *Frequency of Dry Spells*

A dry spell (or rainless day) is defined as one during which rainfall is less than 0.01 in. The frequencies of dry spells of different durations in the years 1947 to 1964 are tabulated by month in *Table 9*. In almost all the months of the year, there are frequencies of dry spells in durations ranging from 1 to 10 days, the frequencies observed decreasing as the durations increase. Dry spells of more than 10 days are confined generally to January, and between May and August. As frequencies of dry spells of different durations seem somewhat similar between months, the data has been tested to determine whether there is any seasonal variation in the frequency of dry spells of different durations. Since the frequencies of five-day durations and above are small, they have been pooled. The expected and the observed frequencies are tabulated by month in *Table 10*.

The χ^2 test has been applied to examine if there is good agreement between observed and expected frequencies (*Table 10*). The total χ^2 observed in all the cells is 100.34 for 44 degrees of freedom which is significant at 5% level. But one notices the contribution of total χ^2 for the different months is relatively bigger for the months of June and November. Excluding these months, the total χ^2 drops to 52.68 for 36 degrees of freedom which is just significant at 5% level. Thus, spells of dry weather show some seasonal variation, the most marked ones observed being in June and November. For any month, the average frequency of dry spell durations of one to five days has been worked out from the 18 years' record, based on all the 12 months as well as for the 10 months excluding June and November (*Table 9*). On an average, a one-day dry spell will occur only

TABLE 9. FREQUENCIES OF DRY SPELLS (1947–1964) AT SUNGEI BULOH

Duration in days	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average per month	Average per month (excluding June & Nov.)
1	59	40	53	62	62	35	57	45	56	57	71	61	658	55	55
2	19	14	18	22	19	20	27	34	31	21	20	29	274	23	23
3	19	13	14	16	13	14	13	15	14	16	4	11	162	14	14
4	15	6	9	5	3	8	10	11	10	4	5	7	93	8	8
5	3	9	5	2	5	8	5	4	3	–	1	2	47	12*	12
6	1	5	2	2	1	5	5	6	2	4	1	2	36		
7	2	2	1	2	1	5	2	2	2	–	1	–	20		
8	–	3	1		–	5	1	–	3	1	1	1	16		
9	2				3	2	2	2	1	–		1	13		
10	3				1	–	1	–		1		1	7		
11	–				1	–	–	–					1		
12	–				–	–	–	1					1		
13	1				–	–	1						2		
14					–	–	–						–		
15					1	1	1						3		
16					–	–							–		
17					–	–							–		
18					–	2							2		
19					1								1		
Total	124	92	103	111	111	105	125	120	122	104	104	115	1336		

* For 5 and more durations.

thrice in any month of a year, a two-day dry spell about 1½ times and a three-day dry spell only once a month in any year.

CONCLUSIONS

No significant trend of annual rainfall with time is detectable at any of the stations with long-term records in the rainfall zone in which Sungei Buloh is situated; this is also true for most of the recognised rainfall regions in Malaysia. Consequently, past rainfall records have been used to predict the probabilities of occurrence of different amounts of rainfall. The observed sequences of wet and dry years in Kuala Lumpur agree closely with the expectations of random distribution. Monthly and annual rainfall at Sungei Buloh have been found to be approximately normal. About 40 years' records are necessary to estimate monthly Means with an accuracy of ± 15%, but 20 years' records are deemed sufficient for an accuracy of ± 10% of the Means in the corresponding rainy days estimate. The annual figures can be estimated even more precisely. The relationship between monthly rainfall and the number of rainy days in a month is linear and shows no clear seasonal influences. As pointed by MANNING (1950), precise confidence limits of the expected monthly and annual rainfall must be regarded as fundamental to the specification of the climatic zones of an agricultural region. The confidence limits of the expected monthly rainfall, the specification of wet and dry seasons, the frequency of occurrence of daily rainfall in excess of certain specified amounts and the frequency of dry spells of different durations in a month—these are all of fundamental con-

TABLE 10. OBSERVED AND EXPECTED FREQUENCIES OF DRY SPELLS (1947–1964) AT SUNGEI BULOH

Duration in days		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1	O	59	40	53	62	62	35	57	45	56	57	71	61	658
	E	61.1	45.3	50.7	54.7	54.7	51.7	61.6	59.1	60.1	51.2	51.2	56.6	658.0
	χ^2	.07	.62	.10	.97	.97	5.39	.34	3.36	.28	.66	7.66	.34	20.76
2	O	19	14	18	22	19	20	27	34	31	21	20	29	274
	E	25.4	18.9	21.1	22.8	22.8	21.5	25.6	24.6	25.0	21.3	21.3	23.6	273.9
	χ^2	1.61	1.27	.46	.03	.63	.10	.08	3.59	1.44	.00	.08	1.24	10.53
3	O	19	13	14	16	13	14	13	15	14	16	4	11	162
	E	15.0	11.2	12.5	13.5	13.5	12.7	15.2	14.6	14.8	12.6	12.6	13.9	162.1
	χ^2	1.07	.29	.18	.46	.02	.13	.32	.01	.04	.92	5.87	.61	9.92
4	O	15	6	9	5	3	8	10	11	10	4	5	7	93
	E	8.6	6.4	7.2	7.7	7.7	7.3	8.7	8.4	8.5	7.2	7.2	8.0	92.9
	χ^2	4.76	.02	.45	.95	2.87	.07	.19	.80	.26	1.42	.67	.12	12.58
5	O	12	19	9	6	14	28	18	15	11	6	4	7	149
&	E	13.8	10.3	11.5	12.4	12.4	11.7	13.9	13.4	13.6	11.6	11.6	12.8	149.0
more	χ^2	.23	7.35	.54	3.30	.21	22.71	1.21	.19	.50	2.70	4.98	2.63	46.55
Total χ^2		7.74	9.55	1.73	5.71	4.70	28.40	2.14	7.95	2.52	5.70	19.26	4.94	100.34

O=Observed frequency E=Expected frequency $\chi^2 = \frac{(O-E)^2}{E}$

Observed χ^2 for 44 d.f. is 100.34, tabled χ^2 for 44 d.f. at 5% sig. level is 60.48.
Excluding June and November, observed χ^2 for 36 d.f. is 52.68, tabled χ^2 for 36 d.f. at 5% sig. level is 51.

cern to the rubber producer in planning the replanting and other plantation activities.

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REFERENCES

DALE, W. L. (1959) The rainfall of Malaya, Part I. *J. trop. Geogr.* **13**, 23.

DALE, W. L. (1960) The rainfall of Malaya, Part II. *J. trop. Geogr.* **14**, 11.

FELLER, W. (1951) *An introduction to probability theory and its applications, Volume I*, New York: John Wiley and Sons Inc.

DEPARTMENT OF CIVIL AVIATION AND METEOROLOGICAL SERVICES, BRITISH BORNEO TERRITORIES (1961) Rainfall statistics of the British Borneo Territories (Sarawak–Brunei–North Borneo), Period 1896–1957.

DRAINAGE AND IRRIGATION DEPARTMENT, FEDERATION OF MALAYA (1961) Hydrological data, rainfall records, 1879–1958.

MANNING, H. L. (1950) Confidence limits of expected monthly rainfall. *J. agric. Sci., Camb.* **40**, 160.

PANCHANG, G. M., RANGARAJAN, R., AND NARAYANAN, R. (1958) Estimation of peak floods of long term return periods. *Proceedings of the Symposium on Meteorological and Hydrological Aspects of Floods and Droughts in India, Indian Meteorological Department*, 131.

WYCHERLEY, P. R. (1963a) Variation in the performances of *Hevea* in Malaya. *J. trop. Geogr.* **17**, 143.

WYCHERLEY, P. R. (1963b) Report on a second visit to North Borneo on behalf of the Rubber Fund Board, November 1962. *Res. Arch. Rubb. Res. Inst. Malaya*, Doc. 20.

WYCHERLEY, P. R. (1966) *Rainfall in Malaysia (Planting Manual No. 12)* Kuala Lumpur: *Rubber Research Institute of Malaya.*

APPENDIX

Herein are set out the methods of calculation adopted in deriving the equations presented in this communication.

Section 2. A sequence of events of the same kind (a sequence of wet or dry years) is called a run and the length of the run is the number of events in it. A run of length r is defined in such a way that one starts from scratch every time a run of length r is completed. For example, in the sequence DDD DW DDD DDD, we have for D, three runs of length 3 as DDD/DW/DDD/DDD, five runs of length 2 as DD/DD/W/DD/DD/DD etc. The Mean recurrence interval of an event for a run of length r (e.g. of dry years D or wet years W), the probability of whose occurrence in any year is p is given by the Equation (FELLER, 1951):

$$U_r = \frac{1-p^r}{(1-p)p^r} \qquad \ldots(1)$$

Section 5. The minimum number (n) of determinations (years of record) necessary for estimating a Mean (of rainfall) to a given level of accuracy (d) from a set of data with a standard deviation (s) is:

$$n = t^2_{n-1}\frac{s^2}{d^2} \qquad \ldots(2)$$

where d is expressed as a percentage of the Mean, t_{n-1} is the student's t-value for $n-1$ degrees of freedom at any desired significance level. In this study, the significance level chosen was 10%.

Section 6. The confidence limits for the expected monthly and annual rainfall values are calculated from

$$\left.\begin{array}{l} P\{\,|x-a| \le ks\,\} = \alpha \\ \text{i.e. } P\{\,a-ks \le x \le a+ks\} = \alpha \end{array}\right\} \qquad \ldots(3)$$

where x refers to the expected monthly or annual rainfall and a is the corresponding true Mean. The observed Means have been taken as the best estimates of the corresponding true Means.

P refers to probability and s is the standard deviation. α is the confidence coefficient, k is a constant depending on α. For normal distribution, when $\alpha=0.67$, k is 0.97 and when $\alpha=0.95$, k becomes 1.96.

Section 8. An equation of the form

$$y^r = a + b \log f \quad (o < r < 1) \qquad \ldots.(4)$$

where a, b and r are constants, would be suitable for depicting the inter-relation between the two variables. When $r=1$, the relation is linear. With Equation (4) fitted, these curves could be used to estimate the rainfall magnitude expected for the different months for frequencies of occurrences like 1/25 or 1/50 (i.e. for return periods of 25 or 50 years, see PANCHANG *et al.*, 1958).