

# FORECASTING COCONUT CROPS USING \* RAINFALL DATA—A PRELIMINARY STUDY

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## SUMMARY

A study on the influence of rainfall on crop variations in coconut is described.

In any attempt to relate coconut yields with rainfall, it would be correct, as in the case of other crops, to consider the rainfall during the critical period of crop development as the effective rainfall. In the case of coconut this critical period is fairly long, covering as much as one year or more. Within a period of one year, extreme changes in the external environment do occur and these changes influence moisture sensitivity appreciably. Therefore the assumption that the palm is equally moisture sensitive throughout this critical period would be erroneous.

The critical period has therefore to be divided into sub-periods within each of which the external environment is more or less uniform and, the weightages to be given to these sub-periods as factors influencing the crop, have to be determined using multiple regression techniques.

It is shown that although the whole year previous to the year of harvest is equally moisture sensitive from the point of view of the stage of crop development, different sub-periods of the year show modified moisture sensitivities apparently as a result of differences in day-length, humidity, temperature and their interactions.

A crop-forecasting formula based on rainfall quantified along these lines is shown to be very efficient ( $R=0.9345$ ).

## INTRODUCTION

If rainfall could be considered a very important natural resource controlling the growth and yield of perennial plants, it is emphatically so in the case of the coconut palm. Scientists and laymen alike agree that rainfall has a profound influence on coconut yields. It is generally conceded that those phenomenal seasonal fluctuations that coconut crops are prone to (being in some years as much as even double the crop of another year) are almost entirely the result of the variations in the rainfall.

Past attempts at quantitatively demonstrating this presumably obvious relationship between rainfall and coconut crops have not yielded any information of a precise nature. Park (1934) observed that a severe drought lasting about 8 months affected the coconut crop even two years later. Patel (1938) observed that inflorescences at the very early stages of development can abort due to drought. Patel (1936) in apparently the only attempt at quantifying this relationship, observed that the rainfall during the dry months over a period of two years prior to the year of harvest had a significant influence on the crop. These and other broad observations made by subsequent workers (cited in the bibliography) have not given clues of sufficiently universal applicability to encourage further work on crop-weather relationships of coconut. Salter and Goode (1967) in their review of "Crop Responses To Water" sum up the position with regard to coconut by stating that "with so great a time lapse between the initiation of leaf and inflorescences primordia and flowering, and with many other inflorescences in various stages of development present at the same time, it has been found difficult to relate accurately growth, flowering or yield responses to any particular climatic condition."

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However the need for precise knowledge of the influence of rainfall (and other weather factors) on coconut crops is growingly felt. Agronomists aiming at a more efficient utilisation of rainfall, other research workers who are disappointed by the fact that fluctuations in yield due to rainfall is masking other variations in which they are deeply concerned, estate managements who would wish to satisfy themselves that the crop realised is within natural limits, and lastly government officials and estate managements who would require crop forecasts for budget purposes—these needs cannot be satisfied until we have more precise knowledge of the problem.

In this paper, it is proposed to give the results of a very recent study on the relationship between rainfall and coconut crops. In Ceylon, our understanding of the problem though not apparently more helpful, yet our thinking in the past has been based on certain clear hypotheses. It is proposed first to set out these various hypotheses which dominated our thinking in the past, and also the predicting efficiency of the relationships arising from them and then against this background to give the present findings which lead us to a more efficient forecasting index.

## MATERIALS AND METHODS

The crop data used in the analysis refer to the annual yields for the period 1935-1966 of a block of coconut about 130 acres in extent at Bandirippuwa Estate of the Coconut Research Institute of Ceylon. The number of bearing palms in the block varied over the period due to the fact some trees have been cut for roads and buildings and some new palms have come into bearing. Due to this reason the yields per bearing palm per year was used in the analysis.

The rainfall data are the monthly rainfall totals obtained from a rain guage maintained in this same block.

The mean annual rainfall is 76 inches ranging from 47.81 inches to 101.20 inches.

The mean maximum day temperature is 87.0°C and the mean minimum night temperature is 74.6°C.

The mean minimum relative humidity is 68.4% during the day and the mean maximum 92.9% during the night.

The soil of the block is mostly gravelly and the topography mostly flat, with about an eighth of the area undulating and tending to promote surface runoff of rain water.

The area is about 2 miles inland and the height above sea level is 100 feet.

## RESULTS

As stated in the introduction, our earlier views on the influence of rainfall on coconut crops, were based on certain specific hypotheses. As a necessary background to an appreciation of the findings of the present study, these earlier hypotheses and the efficiency with which annual crop variations are explained out on the basis of these assumptions will be set out below.

### 1. BACKGROUND :

#### (a) Pre-1956 Period—

##### *Hypotheses—*

- (1) For most fruit trees the period of fruit set can be considered the critical moisture sensitive period. Therefore an adequate supply of water during the period of fruit setting is important.

- (2) The rainfall to be effective it must be well distributed. The number of rainy days is a fairly good index of distribution.

On the basis of these assumptions and with our knowledge that the setting of female flowers pertaining to all the bunches to be harvested in a given year, takes place during a period of one year prior to the year of harvest, it was believed that the crop of a given year is governed by the total rainfall and the number of rainy days of the previous year.

If  $y$  is the yield of nuts,  $x_1$  the total rainfall in the preceding year, and  $x_2$  the number of rainy days in the preceding year, the following relationships were obtained.

Relationships	Correlation coefficient $R$	Coefficient of determination $R^2(\%)$
Yield ( $y$ ) Vs. Rainfall ( $x_1$ ) ... ..	0.4066	16.5%
Yield ( $y$ ) Vs. Rainfall ( $x_1$ ) and rainy days ( $x_2$ ) ... ..	0.4389	19.3%

Predicting formula :— $y = 51.9319 + 0.2401x_1 - 0.061x_2$

( $R^2$  throughout in this paper is the ratio of the sums of squares due to regression to total sums of squares of  $y$ , expressed as a percentage. This indicates the proportion of the variance of the yield explained away by the factor or factors under consideration).

It is observed that contrary to general belief, the inclusion of the distribution index based on the number of rainy days, does not improve on the correlation obtained from the total rainfall alone.

Although the correlation coefficient between total rainfall and the crop is statistically significant, its predicting efficiency is pretty low as shown by the observed and predicted values (Table 1). The distribution of the percentage error in the predictions is shown in Table 2.

**(b) Period 1956-1967—**

*Hypotheses—*

- (1) A particular year's crop is controlled mostly by the previous year's rainfall.
- (2) Considering water loss by surface runoff, percolation and surface evaporation and considering the fact that no amount of extra rain can raise the soil moisture content above field capacity, and also the fact that plant responses to water or any other stimulus generally follow the principle of diminishing returns, it was felt reasonable to believe that there is a maximum rainfall in a month upto which the crop may respond and beyond which it makes no difference for the crop (Abeywardena 1962). In this assumption it was also implicit that under the temperature and humidity conditions obtaining in this area the question of a depressing effect due to excess rainfall can be ruled out. Arising from these assumptions, correlation coefficients between the crop and the annual rainfall based on different hypothetical monthly maximum values were worked out. That is if the hypothetical maximum is (say) 12" in a month, then the rainfall for the year was obtained by adding up all the

monthly totals of rainfall avoiding any rain in excess of 12" in a month. The hypothetical monthly maximum which gave rise to the maximum correlation between crop and rainfall was found to be 14". This was termed "Effective quantity of rainfall" (Abeywardena 1962).

- (3) Rainfall better distributed over the year is more effective. But as noted earlier the number of rainy days is a poor index of distribution. In fact it does not indicate more than what the total rainfall indicates. Accordingly a better distribution index was developed (Abeywardena 1962).

The improvement in our understanding of the crop through the use of this effective quantity of rainfall and the distribution index is indicated by the correlations shown below and the predictions shown in Table 1.

Relationships	R	R <sup>2</sup> (%)
Crop (y) Vs. effective rainfall (x <sub>1</sub> )	0.4869	23.7%
Crop (y) Vs. x <sub>1</sub> and x <sub>2</sub>	0.5717	32.7%

(x<sub>2</sub> is the distribution index)

Predicting formula :— $y = 36.3183 + 0.2635 x_1 + 1.5210 x_2$

It is observed that the relationships as shown by R and the predictions arising therefrom have improved over the predictions based on the previous year's total rainfall. Yet the errors in the predicted values as compared to the observed values are pretty large (Table 1). A comparison of the distribution of percentage errors in the predictions arising from this and the earlier method are shown in Table 2.

## 2. PRESENT FINDINGS

From the above it is clear that our hypotheses regarding rainfall-crop relationships, though broadly reasonable, have not yet helped us to a precise understanding of crop variations. The reason may be that our thinking so far has been restricted to the narrow assumption that the response of a coconut crop to a given rainfall is dependent only on the moisture sensitivity of the stage of crop development during which the presence or absence of rain occurs. For instance it was believed that moisture sensitivity is highest during and around the period of setting of female flowers and therefore the crop is very sensitive to rainfall during this period.

The other possibility of an induction or a restriction of moisture sensitivity arising out of factors exogenous to the palm, has not been given any consideration. Moisture sensitive conditions can arise not only during periods of active development (i.e. endogenous factors) as thought before, but also during periods when the external environment (i.e. exogenous factors) induces increased physiological activity in the palm or increased transpiration or both. Such moisture sensitive periods, irrespective of whether they are conditioned by endogenous or exogenous factors, constitute critical periods during which the presence or absence of an adequate water supply will be reflected in the ultimate crop. This should be particularly so in the case of the coconut palm, which fruits throughout.

The results presented herein refer to the examination of this hypothesis of moisture sensitive periods induced by exogenous environmental factors and also the interaction of endogenous and exogenous factors. The investigation proceeded in progressive stages. Accordingly the results too will be presented in the same order.

### Stage 1—Day length as a factor controlling moisture sensitivity.

It is generally known that reproductive activity in fruit trees is highest during the summer (i.e. the season of long day-length). It is possible that although coconut bears fruit throughout the year, periods of long day-length may be associated with higher reproductive activity and even improved general growth as compared to periods of short day-length.

The day-length in the area under consideration is about 11 hours and 45 minutes in January, increases steadily to a maximum of about 12 hours 30 minutes in June, then decreases to 11 hours and 45 minutes in December.

For the purpose of this investigation, the year was divided into 3 sub-periods viz. January to April with a short day-length, May to August with a long day-length and September to December with a short day-length same as the period January to April.

On the assumption that a period of long day-length, will induce increased plant activity and or increased transpiration, it is to be expected that the crop will be more sensitive to variations in rainfall during periods of long day-length as compared to periods of short day-length.

In order to verify the reasonableness of this assumption, the year previous to the harvest was considered first. Throughout this period the moisture sensitivity due to endogenous factors is constant, because the setting of female flowers of all bunches reaching maturity in the following year takes place throughout this period. Therefore any differences in the correlation coefficients between the crop and these three sub-periods of the year can be reasonably attributed to differences in day-length and its interaction with humidity and temperature.

The correlation coefficients between the crop and the sub-periods of the year previous to the harvest are shown below.

<i>Relationship</i>	<i>Correlation Coefficient (r)</i>
Crop vs. Jan.-April rainfall of previous year ... ..	+0.2528
Crop vs. May-Aug. rainfall of previous year ... ..	+0.5424
Crop vs. Sept.-Dec. rainfall of previous year ... ..	-0.0452

These correlation coefficients show clearly that the period May to August of the previous year is a critical period from the point of moisture sensitivity. The correlation coefficient of 0.5424 for the period May to August is not merely higher than the other two sub-periods, but even higher than that obtained previously when the whole year's rainfall was considered (viz. 0.4066 for the total rainfall and 0.4869 for the effective rainfall). These results confirm the validity of the hypothesis that the crop is more sensitive to variations in rainfall during periods of longer day-length, whatever the reason may be.

However the absence of a correlation between the crop and the rainfall of September to December ( $r = -0.0452$ ) is intriguing. It is a period which considered from the endogenous point of view is as moisture sensitive as the other two periods and considered from the exogenous point of view is as moisture sensitive as the period January to April—both periods being of short day length. This point will be examined in stage 2.

## Stage 2—The depressing effect of excess rainfall—

The absence of a relationship between the crop and the rainfall of September to December when there is an appreciable relationship with the rainfall during the period of January to April which has the same day length, leads us to the next legitimate question. Does rainfall above a certain level have a depressing effect on yields?

This aspect was examined by testing for any curvilinearity in the relationships between the crop and each of these three sub-periods. In the case of the period January to April, there is no indication at all of any depressing effects at higher rainfall. There was a positive response up to 17" in a month and no response beyond 17" in a month. The period May to August too did not show indications of depressing effects (the correlation being 0.5404 for total rainfall and only 0.5418 when the quadratic factor was introduced). During this period there was a positive response upto 19" in a month and no response thereafter. However for the period September to December it was found that the crop response to rainfall was parabolic (the correlation coefficient being—0.0452 for the total rainfall and 0.2195 when the quadratic factor is added on. For some reason or other heavy rainfall during the period September to December seems to depress yields.

However it has to be mentioned that when this diminishing returns aspect of rainfall during September to December was incorporated in to the ultimate crop rainfall equation, a parabolic relationship of the type  $y = a + bx - cx^2$  was not used. It was felt that the positive response of the crop upto a certain level of rainfall and then a depression due to rainfall above this level may not be conditioned by the identical stimuli. Therefore a different approach was adopted. As the positive response was operative upto 14 inches of rainfall in a month, the deficits of the observed rainfall from 14 inches in a month were totalled for the period September to December. This was used as the measure of moisture deficit. The rainfall in excess of 14" in a month totalled for the period was used as the measure of the depressing factor. When these two measures of deficit and excess were used, the correlation coefficient was found to be 0.3852 as compared with the value of 0.2195 obtained when a parabolic relationship was assumed.

Thus it is established, that unlike during the other two periods January to April or May to August, the rainfall of September to December gives rise to increased crops upto about 14 inches of rain in a month and thereafter depresses the crop appreciably.

## Stage 3—Rainfall two years prior to the year of Harvest

The year previous to the year of harvest as mentioned earlier is the critical period from the endogenous point of view as it covers the setting of female flowers and the young stages of all bunches maturing in a given year.

But the initiation of flower primordia occurs as far back as 32 months prior to the opening of an inflorescence. Therefore it is not unlikely that rainfall even prior to the year previous to the year of harvest has some influence on the crop at least to a lesser degree than the year previous to the year of harvest. In fact Park (1934) observed that a severe drought can affect crops even two years later.

This aspect was examined by considering the three sub-periods of the year as before.

The correlation coefficient between the crop and the rainfall of January to April of the year 2 years prior to the year of harvest is—0.2042. Apparently this rainfall has no bearing at all on the crop.

The correlation coefficient between the crop and the rainfall of May to August of this year is substantially high ( $r = + 0.3920$ ). There is a positive response upto 21" rainfall in a month and no response thereafter.

The influence of the rainfall during the period September to December two years prior to the crop year was also examined on the same lines as September to December of the year previous to the year of harvest. The effect of the moisture deficit factor taken singly was apparently effective upto 11" of rain in a month, in the sense that the crop responded positively upto 11" of rain in a month. But when this factor was included in the multiple regression equation its contribution was found to be negligible. The excess rainfall factor showed no depressing effect on yield (the difference in the multiple correlation when this factor was introduced being only a negligible 0.0008).

Thus it is observed that rainfall during the year two years prior to the year of harvest asserts itself on the crop only during the sub-period May to August which has the long day-length. The influence of the other two sub-periods is negligible.

#### **Stage 4—Rainfall during the year of Harvest**

A few bunches maturing at the end of the year of harvest will have their critical stages of development during the early part of the year of harvest. Therefore the first few months of the harvest year too may have some bearing on the crop.

Various periods and various maximum values of monthly rainfall were correlated with the crop. The highest correlation was shown for the period January to May with a maximum of 9" rainfall in a month ( $r=0.3463$ ).

#### **Stage 5—Interaction of rainfall of successive periods**

Apart from the individual effectiveness of the rainfall of these various sub-periods, it is to be reasonably expected that if a particular sub-period which has been droughty is followed by another droughty sub-period, the crop would be depressed more than the sum total effect of these two sub-periods taken severally. Similarly a succession of two sub-periods with good rainfall is reflected favourably on the crop in addition to the favourable effects of the individual sub-periods.

These interactions were examined by including as factors the products of the rainfalls of successive periods. These were :—

1. May-August of 2 years prior x September-December of 2 years prior.
2. September-December of 2 years prior x January-April of previous year.
3. January-April of previous year x May-August of previous year.
4. May-August of previous year x September-December of previous year.
5. September-December of previous year x January-April of harvest year.

All these five interactions when included in the multiple regression equation were found to have an appreciable influence on the crop.

In addition to these first order interactions, another factor indicating the droughtiness of the whole year previous to the year of harvest was also included. The monthly rainfalls were added up for the year excluding any rain in excess of 5" in a month. This is an expression of the droughtiness of a whole year ranging from extremely droughty to droughty. This factor was found to influence the crop very significantly indicating that while different sub-periods of the year had their specific influences on crops, a continued drought of one year's duration depressed crops over and above the influence of the three sub-periods taken severally.

#### **Stage 6—Crop Forecasting Equation**

The factors found to have an appreciable influence on crops on the basis of the above analysis were finally incorporated in a multiple regression equation given below :—

# Observed & Predicted Crops

( Bandirippuwa Estate )

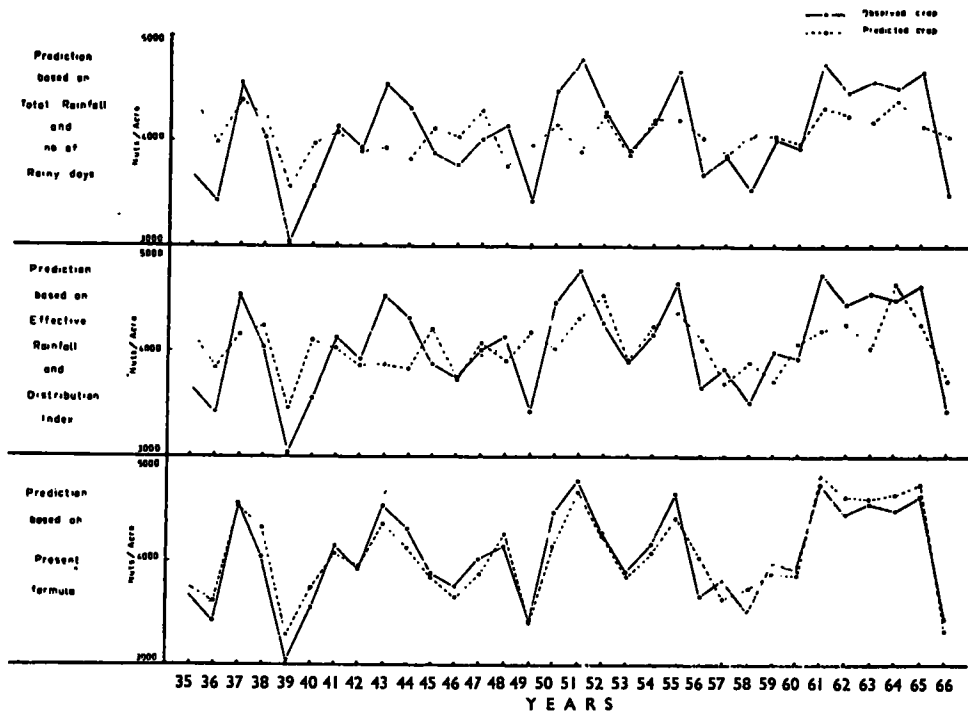


TABLE I

## COMPARISON OF OBSERVED AND PREDICTED CROPS

(Bandirippuwa Estate)

YEAR	Observed crop per acre	Predicted crop based on Total Rainfall and No. of rainy days of previous year			Predicted crop based on Effective Rainfall and distribution index of previous year			Predicted crop based on present findings		
		Nuts per acre	Absolute nuts/acre	% error in prediction	Nuts per acre	Absolute error Nuts/acre	% error in prediction	Nuts per acre	Absolute error Nuts/acre	% error in prediction
1935	3683	4412	729	17.9	4198	515	12.6	3754	71	1.7
1936	3419	3976	557	13.7	3835	416	10.2	3608	189	4.6
1937	4534	4376	158	3.9	4164	370	9.1	4521	13	0.3
1938	4052	4211	159	3.9	4247	195	4.8	4308	256	6.3
1939	3029	3567	538	13.2	3451	422	10.4	3284	255	6.3
1940	3564	3961	397	9.8	4105	541	13.3	3732	168	4.1
1941	4132	4072	60	1.5	4034	98	2.4	4077	55	1.4
1942	3920	3886	34	0.8	3878	42	1.1	3955	35	0.9
1943	4521	3913	608	14.9	3883	638	15.7	4361	160	3.9
1944	4310	3813	497	12.2	3835	475	11.7	4132	178	4.4
1945	3887	4106	219	5.4	4226	339	8.3	3856	31	0.8
1946	3767	4058	291	7.1	3734	33	0.8	3652	115	2.8
1947	4019	4293	274	6.7	4094	75	1.8	3895	124	3.0
1948	4145	3740	405	9.9	3920	225	5.5	4287	142	3.5
1949	3425	3940	515	12.7	4202	777	19.1	3418	7	0.2
1950	4475	4167	308	7.6	4037	438	10.8	4153	322	7.9
1951	4790	3899	891	21.9	4326	464	11.4	4689	101	2.5
1952	4299	4244	55	1.4	4567	268	6.6	4252	47	1.2
1953	3911	3867	44	1.1	3945	34	0.8	3845	66	1.6
1954	4182	4201	19	0.5	4270	88	2.1	4095	87	2.1
1955	4670	4214	456	11.2	4400	270	6.6	4417	253	6.2
1956	3688	4037	349	8.6	4138	450	11.0	4056	368	9.0
1957	3856	3840	16	0.4	3739	117	2.9	3647	209	5.1
1958	3547	4095	548	13.5	3936	389	9.6	3740	193	4.7
1959	4016	4058	42	1.0	3749	267	6.6	3893	123	3.0
1960	3949	3975	26	0.6	4077	128	3.1	3868	81	2.0
1961	4765	4320	445	10.9	4257	508	12.5	4829	64	1.6
1962	4475	4240	235	5.8	4311	164	4.0	4613	138	3.4
1963	4579	4194	385	9.5	4062	517	12.7	4607	28	0.7
1964	4518	4386	132	3.2	4641	123	3.0	4648	130	3.2
1965	4665	4147	518	12.7	4279	386	9.5	4749	84	2.1
1966	3481	4069	588	14.4	3738	257	6.3	3334	147	3.6

**TABLE 2**  
**ERRORS IN PREDICTION**

<i>Percentage Error of Prediction over the mean yield</i>	NUMBER OF YEARS		
	<i>Prediction based on Total Rainfall and No. of Rainy days.</i>	<i>Prediction based on Effective rainfall and distribution index.</i>	<i>Prediction based on present findings</i>
Less than 4% ... ..	11	9	22
4% to less than 6% ... ..	2	3	5
6% to less than 8% ... ..	3	4	4
8% to less than 10% ... ..	4	4	1
10% to less than 12% ... ..	2	6	—
12% to less than 14% ... ..	6	4	—
14% to less than 16% ... ..	2	1	—
16% and over ... ..	2	1	—
Mean Error % ... ..	7.9%	7.7%	3.3%

(APPENDIX I)

RAINFALL 1933 - 1966 (Bandirippuwa Estate)

Month	1933	1934	1935	1936	1937	1968	1939	1940	1941	1942
January ...	3.40	8.14	0.17	1.35	2.42	1.64	8.59	0.00	1.68	1.35
February ...	4.16	1.84	1.59	2.34	2.32	9.16	0.54	0.10	0.15	0.81
March ...	2.14	5.36	2.77	12.93	2.85	9.75	0.54	4.13	1.02	3.87
April ...	7.31	12.04	4.39	0.67	13.65	6.64	7.03	7.55	9.15	14.08
May ...	11.75	12.38	9.79	27.70	14.68	2.79	7.30	14.51	7.25	14.04
June ...	8.90	14.72	7.92	8.48	3.19	0.76	6.45	8.89	6.24	6.17
July ...	8.97	0.29	0.42	2.61	3.43	0.97	7.31	1.91	2.18	2.26
August ...	8.66	1.03	5.85	0.56	0.66	4.19	7.75	3.34	4.21	3.82
September ...	3.38	0.30	1.39	7.31	16.27	3.97	1.82	3.61	7.71	0.85
October ...	8.30	14.97	16.63	7.48	7.80	2.93	8.64	13.72	9.19	6.67
November ...	7.78	27.84	11.69	12.90	17.93	1.19	12.03	21.31	20.35	7.51
December ...	2.24	1.17	4.33	8.93	2.21	3.82	2.07	2.85	2.84	7.94
Total ...	76.99	100.08	66.94	93.26	87.41	47.81	70.07	81.92	71.97	69.37

Month	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952
January ...	2.25	0.94	0.02	0.19	5.79	1.13	1.28	0.38	5.70	4.10
February ...	0.92	2.77	0.17	0.39	4.38	0.93	0.48	8.06	0.72	4.70
March ...	3.02	12.07	6.85	8.35	5.36	11.12	0.17	1.28	10.10	0.23
April ...	5.34	9.14	6.32	8.88	3.98	7.16	17.93	9.00	9.81	3.71
May ...	8.86	4.72	2.50	10.59	7.19	4.51	20.86	5.58	18.55	11.54
June ...	6.82	7.00	6.57	6.03	8.32	8.17	11.47	8.92	2.17	7.40
July ...	1.67	1.07	3.94	0.78	6.83	1.47	7.23	3.55	8.91	0.40
August ...	2.85	2.49	0.57	1.51	5.02	7.50	4.53	2.75	0.20	3.10
September ...	0.98	12.11	1.00	3.98	3.36	1.36	2.94	3.83	12.85	4.12
October ...	13.72	10.06	26.83	19.20	6.91	20.71	10.58	15.80	4.89	11.90
November ...	13.67	18.77	11.48	25.01	0.56	5.30	6.49	5.68	18.35	7.80
December ...	4.96	10.33	5.88	12.98	2.23	3.99	2.41	2.83	1.84	4.34
Total ...	65.06	91.47	72.13	97.89	59.93	73.35	86.37	67.66	94.09	63.34

Month	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962
January ...	4.24	4.84	1.28	5.01	0.91	1.15	0.93	0.57	1.88	1.02
February ...	3.16	2.06	1.36	0.61	3.38	1.34	0.59	3.30	4.55	4.98
March ...	6.28	12.82	3.49	4.75	0.19	8.40	2.28	2.02	7.35	3.17
April ...	15.00	14.28	12.24	7.65	8.48	13.69	8.88	17.59	10.34	7.52
May ...	0.89	11.81	17.29	3.83	13.01	26.20	10.76	14.10	13.49	18.48
June ...	4.49	1.10	4.93	8.22	8.15	5.23	5.96	3.50	14.25	8.66
July ...	21.69	4.89	1.00	0.24	2.03	1.15	9.72	15.53	4.60	1.92
August ...	0.71	4.48	0.21	0.33	2.29	3.59	3.40	0.91	5.41	4.12
September ...	3.89	3.95	16.73	3.98	0.66	1.21	4.90	2.15	9.56	4.43
October ...	22.08	13.43	11.06	7.79	6.44	7.57	11.14	14.07	4.11	20.00
November ...	5.11	6.41	11.82	9.43	20.94	5.29	11.49	12.64	8.85	3.64
December ...	0.76	13.63	2.10	1.43	12.32	1.64	1.13	1.02	1.49	0.46
Total ...	88.30	93.70	83.51	53.27	78.80	76.46	71.18	87.40	85.88	78.40

Month	1963	1964	1965	1966
January ...	5.27	2.45	0.45	2.04
February ...	3.14	2.99	0.58	3.70
March ...	7.97	10.58	1.29	2.76
April ...	6.17	1.60	5.09	11.91
May ...	17.08	17.22	9.16	2.16
June ...	8.11	8.12	1.53	2.94
July ...	6.31	4.51	1.92	2.52
August ...	2.98	3.53	11.66	0.36
September ...	10.28	5.47	3.57	16.52
October ...	15.91	12.61	20.67	9.84
November ...	14.21	6.67	3.42	6.25
December ...	3.78	1.72	8.63	4.68
Total ...	101.20	77.47	67.97	65.68

$$y = 8.9796 + 0.0180 x_1 - 0.6017 x_2 - 0.5709 x_3 - 0.5960 x_4 \\ + 0.1289 x_5 + 0.8367 x_6 + 0.0221 x_7 + 0.0171 x_8 \\ + 0.0334 x_9 + 0.0229 x_{10} - 0.0125 x_{11} + 0.4801 x_{12}$$

(Factors which are not significant and not close to significance have been deleted in the above equation. The factors  $x_1$  to  $x_{12}$  have been explained in Appendix 2).

Multiple Correlation : R = 0.9345  
 Coefficient of determination :  $R^2$  = 87.3%

The predicted crops based on this equation are shown in Table 1 and a comparison of the distribution of errors in prediction with those of the earlier two methods is shown in Table 2. While the proportion of the variance in yield explained away by the earlier methods ranged from 16% to 32%, the present findings account for 87% of the variance of the yield and the multiple correlation coefficient is 0.9345. The predictions based on this formula are remarkably close to the observed values (FIG. 1).

### DISCUSSION

The influence of a particular spell of rainfall on the yield of most fruit crops is dependent on the moisture sensitivity of the stage of development of the crop during the spell of rainfall. Accordingly in past attempts to understand the variation in the yearly yields of coconut crops, the rainfall during the previous year was the main consideration. This period constitutes the critical period from the point of view of an year's crop because it covers the period of setting of all bunches that mature during the harvest year.

This approach has yielded satisfactory results for most fruit crops although not for coconut. In most fruit crops the fruiting period is short and therefore any interaction between rainfall and other environmental factors can be considered negligible. But in the case of coconut which fruits throughout such interactions are to be expected. When one refers to the crop of one year, the critical period is a minimum of one year. Differences in the exogenous environment occurring within this critical period of one year can influence moisture sensitivity appreciably—may be either due to their influence on plant activity and or uptake of moisture. Therefore although the whole year prior to the crop year is equally moisture sensitive from the endogenous point of view, different sub-periods of this critical period may have varying moisture sensitivities due to differences in day-length and or other environmental factors. Apparently it is this failure on our part to discriminate between moisture sensitive conditions arising from endogenous factors (i.e. critical periods of crop development) and moisture sensitive conditions induced or suppressed by the external environment, that has deprived us so far of a clear understanding of crop-weather relationships of coconut.

The correct approach appears to be to divide the year into a number of sub-periods within each of which the external environment can be considered more or less uniform. The weight-ages to be given to rainfalls during these sub-periods vis-a-vis the crop can be determined using multiple regression techniques.

The results of this study amply confirm that the period May to August with a longer day-length is more moisture sensitive. The sub-periods January to April and September to December are not only less moisture sensitive but also differ widely in their moisture sensitivities in spite of the fact that their day-lengths are identical. During the period January to April there are no harmful effects due to heavy rainfall whereas during the period September-December any rain in excess of 14" in a month is significantly harmful.

In order to understand this surprising feature, it may be helpful to examine the temperature and humidity conditions of the sub-periods (shown below).

PERIOD	Mean Max. Day Temp.	Mean Min. Day Humidity
January-April ... ..	89.1°C	60.7%
May-August ... ..	85.9°C	74.6%
September-December ... ..	86.0°C	69.9%

It is observed that during January to April the temperature is high and the humidity low whereas during September-December the temperature is low and the humidity is high. Conditions during January to April are therefore conducive to high transpiration intensity whereas during the period September to December it is not so. Does this mean that excess rainfall is harmful during periods when the exogenous environment is not conducive to free transpiration ?

The period May to August also has a low temperature and high humidity — conditions even worse than during September to December from the point of view of transpiration intensity. But this period apparently has a high moisture sensitivity and there are no indications of harmful effects due to excess rainfall. The question then poses itself whether the absence of such harmful effects during this period May to August is due to the fact that a longer day-length implying a longer duration of active transpiration offsets any disadvantages arising from the low transpiration intensity brought about by the less favourable external environment ?

The absence of harmful effects due to heavy rainfall during May to August may also be explained otherwise. The rain (South-west monsoon) of May-August is spread out over a longer period as compared to the inter-monsoonal heavy rains of September to December where all the rain is concentrated within October and November. It may also be due to the fact that the May-August rains follow a prolonged dry period commencing in December of the previous year and therefore the soil can take up appreciably more water to replenish the depleting after effects of the long dry period. Whereas the rains of September to December follow almost immediately after the rains of May to August and therefore may be in excess.

In this preliminary stage of our studies, it is not proposed to stress on any specific reasons for these phenomena. Further analyses of this nature in several other areas, with different climatic conditions in Ceylon are to be carried out immediately as part of the "crop forecasting project" of the Coconut Research Institute of Ceylon. It is hoped to get a clearer picture of these interacting influences after further studies.

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## APPENDIX

### Index to $x$ in Formula

- $x_1$  — May—August two years (Maximum 21")
- $x_2$  — January—April previous year (Maximum 17")
- $x_3$  — May—August previous year (Maximum 19")
- $x_4$  — September—December previous year (Excess of 14")
- $x_5$  — September—December previous year (No. of rainy day in excess of 18 days in a month).
- $x_6$  — January—May of harvest year (Maximum 9")
- $x_7$  — Product of (1) May—August 2 years prior (Maximum 6")  
and (2) September—December 2 years prior (Maximum 9")
- $x_8$  — Product of (1) September—December 2 years prior (Maximum 11")  
and (2) January—April of previous year (Maximum 17")—with an effective maximum of 450
- $x_9$  — Product of (1) January—April of previous year (Maximum 17")  
and (2) May—August of previous year (Maximum 19")—with effective maximum of 600
- $x_{10}$  — Product of (1) May—August of previous year (Maximum 11")  
and (2) September—December of previous year (Maximum 14")
- $x_{11}$  — Product of (1) September—December of previous year (Maximum 11")  
and (2) January—April of harvest year (Maximum 17")
- $x_{12}$  — Previous year's rainfall with an effective monthly maximum of 5" (indicating a prolonged drought of one year).