STUDY OF THE RELATIONSHIP BETWEEN CACAO YIELD AND RAINFALL

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(The data used in this study have been taken from observations on a progeny testing trial which forms part of the Cacao Improvement Programme at the Lowlands Experimental Station, Keravat. The trial is laid down as a randomized block with four replications. Each replication contains ten plots of forty-six trees, the trees in each plot being the progeny of one of ten field selections made in 1947.

Seeds for the progeny used were planted in the nursery in December, 1947, and transferred to the field in March, 1948. Seedlings were planted 15 ft. x 15 ft. on the square and have had orthodox *Leucaena glauca* shade. The total numerical yield of pods for all forty plots was used in the present study.)

Method.—

The cacao pods are harvested roughly every twenty-one days but this period is not exact and not quite regular. Yields, therefore, had to be adjusted to a monthly basis by calculation. This was done as follows :—

Suppose the cacao pods were harvested on 7th March and again on the 1st April. The period between the harvest is 25 days. Suppose that the yield on 1st April was 2,904 pods, i.e., the average daily yield from 7th March to 1st April = 2,904 ÷ 5 = 116.1 pods. Of the 25 days concerned, 24 occurred in March and one in April. Thus of the 2,904 pods yielded 116.1 × 24 can be allocated to March and 116.1 × 1 can be allocated to April. By this method yields were calculated on a monthly basis and graphed (Figure 1). Monthly rainfall figures were also graphed (Figure 2). From an inspection of these graphs in relation to each other, it seemed possible that the yield at any point on the time scale was positively correlated with the rainfall three months before and negatively correlated with the rainfall about five months before.

Correlation coefficients were therefore calculated for—

1. Yield with rainfall 3 months before.
2. Yield with rainfall 4 months before.
3. Yield with rainfall 5 months before.
4. Yield with rainfall 6 months before.

Results.—

1. A correlation coefficient of + 0.58 was obtained. This is highly significant (P = 0.01).
2. A correlation coefficient of —0.69 was obtained. This is highly significant (P = 0.001).
3. A correlation coefficient of —0.79 was obtained. This is highly significant (P = 0.001).
4. A correlation coefficient of —0.19 was obtained. This is not significant (P = 0.3).

Discussion.—

It can be seen from the following figures that it usually takes six months for a ripe pod to be produced from the time of pollination.

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Time for Pollination to Maturity.—

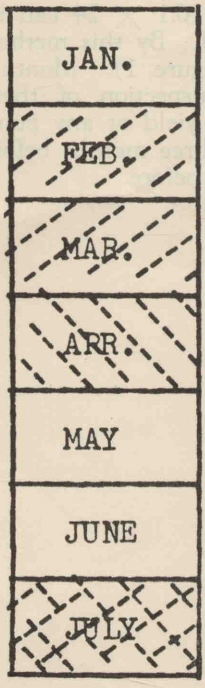
(Figures taken from data re self-pollination.)

Pod No.	Date Pollinated	Date Harvested	No. Days	Month (30) days
1	14.11.1951	2.6.1952	200	6.6
2	15.11.1951	2.6.1952	199	6.6
3	23.11.1951	2.6.1952	191	6.4
4	24.11.1951	2.6.1952	190	6.3
5	28.11.1951	2.6.1952	186	6.2
6	7.12.1951	2.6.1952	177	5.9
7	18.12.1951	2.6.1952	166	5.5
8	20.12.1951	2.6.1952	164	5.5
9	21.12.1951	2.6.1952	163	5.4
10	28.11.1951	2.6.1952	186	6.2
11	1.12.1951	2.6.1952	184	6.1
12	12.1.1952	30.6.1952	169	5.6
13	1.12.1951	2.6.1952	184	6.1
14	7.2.1952	14.8.1952	188	6.3

Total = 2,547.

Mean = 182 days or 6.06 months.

The results can be discussed better with an hypothetical example.



(Figure 3)

The yield in July is positively correlated with rainfall in April and negatively correlated with rainfall in February and March. There is no relationship between yield in July and rainfall in January (Figure 3).

It can be seen that pods harvested in July will have resulted from pollination of flowers in January. Thus, it appears that :—

1. There is no regular relationship between rainfall at the time of pollination and yield.
2. There is no regular relationship between rainfall for the first 3-4 weeks after pollination and yield.
3. There is a distinct negative correlation between rainfall for the period 4-12 weeks after pollination and yield.
4. There is a distinct positive correlation between rainfall for the period 12-16 weeks after pollination and yield.

1. *Effect of Rainfall on Pollination.—*

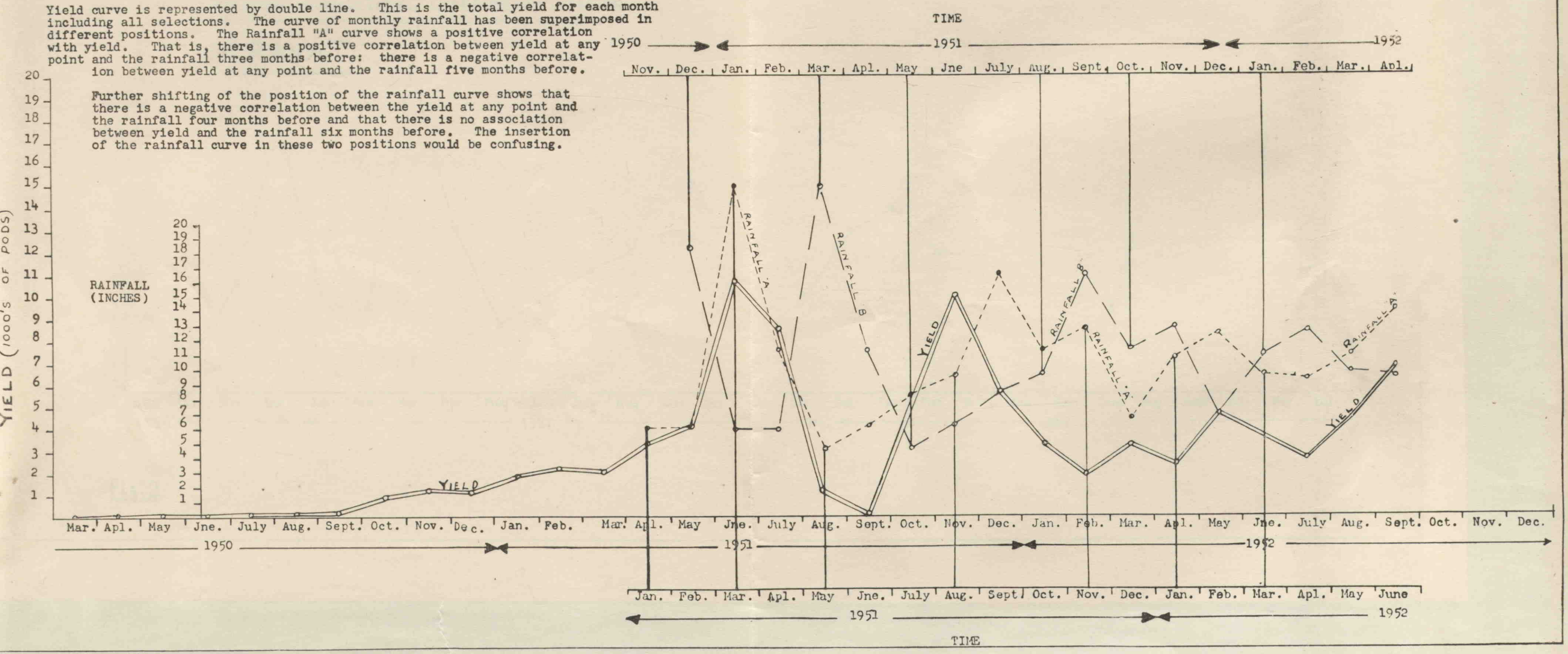
Let us consider first, the evidence that rainfall does not appear to influence pollination in any regular manner. It cannot be concluded that rainfall never has any influence on pollination.

If the rainfall graph is superimposed on the yield graph so that yield corresponds with the rainfall six months previously, it is apparent that there is no regular relationship between the two lines. This is proven by one of the correlation tests. However, it can be seen that sometimes there appears to be a negative correlation and sometimes a positive correlation. This could mean nothing at all or it could mean that two or more interacting factors

RELATIONSHIP BETWEEN YIELD OF CACAO (PODS) AND RAINFALL.

Yield curve is represented by double line. This is the total yield for each month including all selections. The curve of monthly rainfall has been superimposed in different positions. The Rainfall "A" curve shows a positive correlation with yield. That is, there is a positive correlation between yield at any point and the rainfall three months before: there is a negative correlation between yield at any point and the rainfall five months before.

Further shifting of the position of the rainfall curve shows that there is a negative correlation between the yield at any point and the rainfall four months before and that there is no association between yield and the rainfall six months before. The insertion of the rainfall curve in these two positions would be confusing.



RAINFALL

LOWLANDS AGRICULTURAL EXPERIMENT STATION

KERAVAT.

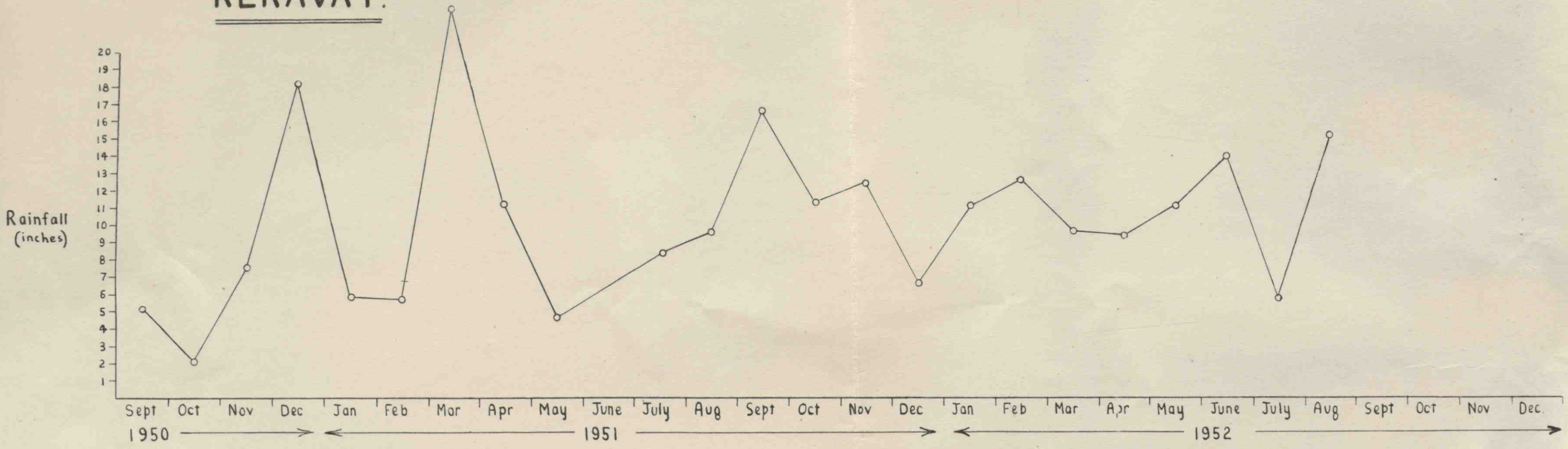


Fig. 2

(of which rainfall is one) determine the amount of setting. The most that can be said at present is that there is no evidence to suggest that rainfall at the time of pollination exerts a significant effect on yield. Pollination does not appear to be the limiting factor.

2. *Effect of Rainfall for the First 3-4 Weeks after Pollination.*—

Let us consider the evidence that rainfall for the first 3-4 weeks after pollination does not effect yield in any regular manner. That is, that the extent of cherelle wilt is not effected in a regular manner by rainfall for the first 3-4 weeks following pollination. There are several possible explanations of this; (Assuming that cherelle wilt is largely caused by pathogens) :—

(*a*) That for one reason or another the very young cherelles escape infection for the first few weeks of development;

(*b*) That the very young cherelles are resistant to the pathogen(s) ;

(*c*) That infection of the young cherelles by the pathogen(s) depends on prior inoculation by sucking and biting insects, it being assumed that cherelles largely escape insect attack on account of their size until they are over three weeks old; and

(*d*) That the cherelles are able to outgrow the pathogen for the first 3-4 weeks, after pollination irrespective of rainfall. Thereafter high rainfall leads to ideal growing conditions for the pathogen(s) so that they are able to kill the cherelle and low rainfall leads to poor growing conditions for the pathogens so that the cherelle is still able to outgrow the pathogen(s).

Monthly figures showing the extent of cherelle wilt cannot be produced to corroborate this explanation, but field observations agree with the findings. At the time of writing there have been five consecutive wet overcast days.

A random selection of 18 trees gave the following counts :—

	Tree No.	No. Dead Cherelles	No. Healthy Cherelles
	1	22	33
Date of Count—	2	6	9
28th November, 1952	3	8	18
	4	7	3
Rainfall (points)—	5	47	4
21st November, 1952 15	6	18	2
22nd November, 1952 9	7	28	5
23rd November, 1952 82	8	5	4
24th November, 1952 304	9	2	0
25th November, 1952 55	10	1	0
	11	27	17
	12	31	8
	13	15	3
	14	3	52
	15	32	0
	16	28	5
	17	14	2
	18	38	8

A count of this nature is of no particular value as many of the cherelles counted may have been adhering to the tree for some time. It is proposed to carry out a systematic count over a twelve-month period, in order to find out whether the above explanation of results is correct. In the meantime, the figures given in the above table appear to corroborate the explanation given. Another significant fact is that of all the dead cherelles counted 90 per cent. were estimated to be from 3-8 weeks old.

3. *Effect of Rainfall for the Period 4-12 Weeks after Pollination.*—

There appears to be indisputable evidence that the principal factor limiting yield is the rainfall during the period 4-12 weeks after pollination. The most obvious explanation of this is that high rainfall during this period leads to a high rate of infection of cherelles by such organisms as *Phytophthora, Colletotrichum* and *Diplodia.* This leads to excessive cherelle wilt which results in a depression of yield 4-5 months later. It would be difficult to interpret the results any other way. It seems unlikely that the excessive cherelle wilt during high rainfall could have a purely physiological explanation.

4. *Effect of Rainfall for the Period 12-16 Weeks after Pollination.*—

It was found that rainfall during this period is positively correlated with yield. Bearing in mind the fact that yield is measured by the number of pods produced, there are two possible explanations of this result :—

(*a*) That high rainfall at this stage leads to a very rapid increase in the growth rate of pods which have survived the first 12 weeks so that once again the pathogen(s) are simply outgrown. Low rainfall during this period would give the pathogen(s) a decided advantage resulting in further loss of young pods. On this explanation, therefore, after the age of 12 weeks, the higher the rainfall, the lower the loss of pods. Field observations indicate that pods are still lost after the age of 12 weeks.

(*b*) After the age of 12 weeks, pods are most resistant to the pathogens and that the time required for maturation of the pod is directly proportioned to the rainfall for the period 12-16 weeks after pollination. It will be seen from the figures given that the time from pollination to ripe pod varies from 5½ to 6½ months.

JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY

Taking flowers pollinated in January, a certain percentage will have survived at the end of March depending on the rainfall during February and March.

It is suggested that the rainfall in April may determine whether the maturation period will be 5½ or 6½ months or somewhere in between. If the rainfall in April is high, the maturation period is reduced to about 5½ months and many of the pods which would normally have ripened in August would now ripen in July, thereby increasing the yield for this month. Conversely, if the rainfall in April is low, the maturation period is increased to 6½ months and many of the pods which would normally have ripened in July would now ripen in August thereby depressing the yield for July.

Although both of the above explanations appear to be feasible, the latter explanation appears to be the more satisfactory.

Summary.—

If it can be accepted that any influence of rainfall on yield for the period 4-12 weeks after pollination of the flowers, is exerted by a direct influence on pathogenic organisms causing cherelle wilt, the following conclusions can be drawn :—

(1) There is no evidence to support the view that rainfall has a regular significant effect on pollination.

(2) There is no evidence to support the view that pollination is an important factor limiting yield.

(3) There is relatively little cherelle wilt for the first 3-4 weeks after pollination irrespective of rainfall.

(4) For the period 4-12 weeks after pollination, high rainfall results in excessive cherelle wilt and low rainfall results in little cherelle wilt.

(5) For the period 12-16 weeks after pollination, high rainfall has the effect of increasing yield and the corollary is also true.

RELEVANT RAINFALL AND YIELD FIGURES.

Year	Month	Yield (100's pods)	Rainfall (points)	No. days on which rain fell.
1950	September	....	532	9
	October	..	210	8
	November	....	778	12
	December	....	1826	17
1951	January	....	590	18
	February	....	566	10
	March	....	2242	25
	April	33.1	1124	11
	May	40.9	453	12
	June	107.0	613	16
	July	84.0	823	20
	August	10.7	949	18
	September	0.08	1654	19
	October	62.3	1131	17
	November	99.8	1288	19
	December	54.0	658	11
1952	January	32.4	1089	10
	February	17.7	1249	18
	March	31.6	955	19
	April	23.2	934	16
	May	44.0	1090	15
	June	34.8	1397	23
	July	25.9	565	19
	August	42.0	....	....
	September	66.2	....	....

RELATIONSHIP BETWEEN MONTHLY YIELD OF CACAO.
PODS AND RAINFALL FOR THE THIRD PREVIOUS MONTH.

Month	(inches) Rainfall (X)	Month	(100's pods) Yield (Y)	X^2	Y^2	XY
Jan., ... '51	5.90	Apr., ... '51	33.1	34.81	1,095.61	195.29
Feb., ... '51	5.66	May, ... '51	40.9	32.04	1,672.81	231.49
Mar., ... '51	22.40	June, ... '51	107.0	501.76	11,449.00	2,396.80
Apr., ... '51	11.20	July, ... '51	84.4	125.44	7,123.36	945.28
May, ... '51	4.53	Aug., ... '51	10.7	20.52	114.49	48.47
June, ... '51	6.13	Sept., ... '51	.08	37.58	0.01	0.49
July, ... '51	8.23	Oct., ... '51	62.3	67.73	3,881.29	512.73
Aug., ... '51	9.49	Nov., ... '51	99.8	90.06	9,960.04	947.10
Sept., ... '51	16.50	Dec., ... '51	54.00	272.25	2,916.00	891.00
Oct., ... '51	11.30	Jan., ... '52	32.4	127.69	1,049.76	366.12
Nov., ... '51	12.90	Feb., ... '52	17.7	166.41	313.29	228.33
Dec., ... '51	6.58	Mar., ... '52	31.6	43.30	998.56	207.93
Jan., ... '52	10.90	Apr., ... '52	23.2	118.81	538.24	252.88
Feb., ... '52	12.50	May, ... '52	44.0	156.25	1,936.00	550.00
Mar., ... '52	9.55	June, ... '52	34.8	91.20	1,211.04	332.34
Apr., ... '52	9.34	July, ... '52	25.9	87.24	670.81	241.91
May, ... '52	10.90	Aug., ... '52	42.0	118.81	1,764.00	457.80
June, ... '52	14.00	Sept., ... '52	66.2	196.00	4,382.44	926.80
Total	188.01	....	810.08	2,287.90	51,076.75	9,732.76

$N = 18 \quad \overline{X} = 10.45 \quad (SX)^2 = 35{,}347.76$

$\overline{Y} = 45.00 \quad (SY)^2 = 656{,}229.61$

$$^{r}XY = \frac{NS(XY) - SX.SY}{\sqrt{[NS(X)^2 - (SX)^2]\ \ [NS(Y)^2 - (SY)^2]}}$$

$$= \frac{18 \times 9732.76 - 188.01 \times 810.08}{\sqrt{(18 \times 2,287.90 - 35,347.76)\ (18 \times 51076.75 - 656,229.61)}}$$

$$= + 0.584$$

$$t = \frac{r \sqrt{N - 2}}{\sqrt{1 - r^2}} = \frac{0.584 \sqrt{16}}{1 - 0.341056}$$

$$= 2.88$$

$N = 18 \qquad P = .01$

Conclusion—

There is a highly significant positive correlation between yield of cacao pods and the rainfall during the third previous month.

RELATIONSHIP BETWEEN YIELD OF CACAO PODS AND RAINFALL FOR THE FOURTH PREVIOUS MONTH.

Month	Rainfall X	X^2	Month	Yield Y	Y^2	XY
Dec., ... '50	18.30	334.89	Apr., ... '51	33.1	1,095.61	605.73
Jan., ... '51	5.90	34.81	May, ... '51	40.9	1,672.81	241.31
Feb., ... '51	5.66	32.04	June, ... '51	107.0	11,449.00	605.62
Mar., ... '51	22.40	501.76	July, ... '51	84.0	7.123.36	188.16
Apr., ... '51	11.20	125.44	Aug., ... '51	10.7	114.49	119.84
May, ... '51	4.53	20.52	Sept., ... '51	0.08	0.01	0.40
June, ... '51	6.13	37.58	Oct., ... '51	62.3	3,881.29	381.90
July, ... '51	8.23	67.73	Nov., ... '51	99.8	9,960.04	821.35
Aug., ... '51	9.49	90.06	Dec., ... '51	54.0	2,916.00	512.46
Sept., ... '51	16.50	272.25	Jan., ... '52	32.4	1,049.76	534.60
Oct., ... '51	11.30	127.69	Feb., ... '52	17.7	313.29	200.01
Nov., ... '51	12.90	166.41	Mar. .... '52	31.6	998.56	407.64
Dec., ... '51	6.58	43.30	Apr., ... '52	23.2	538.24	152.66
Jan., ... '52	10.90	118.81	May, ... '52	44.0	1,936.00	479.60
Feb., ... '52	12.50	156.25	June, ... '52	34.8	1,211.04	435.00
Mar. .... '52	9.55	91.20	July, ... '52	25.9	670.81	247.35
Apr., ... '52	9.34	87.24	Aug., ... '52	42.0	1,764.00	392.28
May, ... '52	10.90	118.81	Sept., ... '52	66.2	4,384.44	721.58

$SX = 192.31 \qquad S(X)^2 = 2426.79 \qquad SY = 810.08$

$S(Y)^2 = 51,076.75 \qquad S(XY) = 7,047.49$

$(SX)^2 = 36,983.14 \qquad (SY)^2 = 656,229.61 \qquad SX\ SY = 155,786.48$

$$^{r}XY = \frac{NS(XY) - SX.SY}{\sqrt{[NS(X)^2 - (SX)^2]\ \ [NS(Y)^2 - (SY)^2]}}$$

$$= \frac{18 \times 7047.49 - 155,786.48}{\sqrt{(18 \times 2,426.79 - 36,983.14)\ (18 \times 51,076.75 - 656,229.61)}}$$

$$= - 0.689$$

$$t = \frac{r \sqrt{N - 2}}{\sqrt{1 - r^2}} = \frac{0.69 \sqrt{16}}{1 - 0.476}$$

$$= 5.26$$

$P = 0.001$

Conclusion—

There is a highly significant negative correlation between yield of cocoa pods and the rainfall during the fourth previous month.

RELATIONSHIP BETWEEN YIELD OF CACAO PODS AND RAINFALL FOR THE FIFTH PREVIOUS MONTH.

Month	Rainfall X	X²	Month	Yield Y	Y²	XY
Dec., ... '50	18.30	334.89	May, ... '51	40.9	1,672.81	748.47
Jan., ... '51	5.90	34.81	June, ... '51	107.0	11,449.00	631.30
Feb., ... '51	5.66	32.04	July, ... '51	84.4	7,123.36	477.70
Mar., ... '51	22.40	501.76	Aug., ... '51	10.7	114.49	239.68
Apr., ... '51	11.40	125.44	Sept., ... '51	0.08	0.01	0.09
May, ... '51	4.53	20.52	Oct., ... '51	62.3	3,881.29	282.22
June, ... '51	6.13	37.58	Nov., ... '51	99.8	9,960.04	611.77
July, ... '51	8.23	67.73	Dec., ... '51	54.0	2,916.00	444.42
Aug., ... '51	9.49	90.06	Jan., ... '52	32.4	1,049.76	307.48
Sept., ... '51	16.50	272.25	Feb., ... '52	17.7	313.29	292.05
Oct., ... '51	11.30	127.69	Mar., ... '52	31.6	998.56	357.08
Nov., ... '51	12.90	166.41	Apr., ... '52	23.2	538.24	299.28
Dec., ... '51	6.58	43.30	May, ... '52	44.0	1,936.00	289.52
Jan., ... '52	10.90	118.81	June, ... '52	34.8	1,211.04	379.32
Feb., ... '52	12.50	156.25	July, ... '52	25.9	670.81	323.75
Mar., ... '52	9.55	91.20	Aug., ... '52	42.0	1,764.00	401.10
Apr., ... '52	9.34	87.24	Sept., ... '52	66.2	4,384.44	618.31
	181.41	2307.98		766.98	49,981.14	6.703.54

$$^{r}XY = \frac{NX(XY) - SX.SY}{\sqrt{[NS(X)^2 - (SX)^2]\ [NS(Y)^2 - (SY)^2]}}$$

$$= \frac{17 \times 6,703.54 - 140,951.94}{\sqrt{(17 \times 2,307.98 - 32,909.59)\ (17 \times 49,981.14 - 603,697.92)}}$$

$$= -\ 0.79$$

$$t = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}} = \frac{0.97 \times 3.87}{\sqrt{1 - 0.6241}}$$

$$= 5.16$$

N = 17 P = .001

Conclusion—

There is a very highly significant negative correlation between cocoa yields and rainfall for fifth previous month.

RELATIONSHIP BETWEEN YIELD OF CACAO PODS AND RAINFALL FOR THE SIXTH PREVIOUS MONTH.

Month	Rainfall X	X^2	Month	Yield Y	Y^2	XY
Dec., ... '50	18.30	334.89	June, ... '51	107.0	11,449.00	1,958.1
Jan., ... '51	5.90	34.81	July, ... '51	84.0	7,123.36	495.6
Feb., ... '51	5.66	32.04	Aug., ... '51	10.7	114.49	60.566
Mar., ... '51	22.40	501.76	Sept., ... '51	0.08	0.01	1.792
Apr., ... '51	11.20	125.44	Oct., ... '51	62.3	3,881.29	697.760
May, ... '51	4.53	20.52	Nov., ... '51	99.8	9,960.04	452.094
June, ... '51	6.13	37.58	Dec., ... '51	54.0	2,916.00	331.020
July, ... '51	8.23	67.73	Jan., ... '52	32.4	1,049.76	266.652
Aug., ... '51	9.49	90.06	Feb., ... '52	17.7	313.29	167.973
Sept., ... '51	16.50	272.05	Mar., ... '52	31.6	998.56	521.400
Oct., ... '51	11.30	127.69	Apr., ... '52	23.2	538.24	262.160
Nov., ... '51	12.90	166.41	May, ... '52	44.0	1,936.00	567.600
Dec., ... '51	6.58	43.30	June, ... '52	34.8	1,211.04	228.984
Jan., ... '52	10.90	118.81	July, ... '52	25.9	670.81	282.310
Feb., ... '52	12.50	156.25	Aug., ... '52	42.0	1,764.00	525.000
Mar., ... '52	9.55	91.20	Sept., ... '52	66.2	4,382.44	632.210
	SX = 172.07	$S(X)^2$ = 2,220.54		SY = 735.68	$S(Y)^2$ = 48,308.33	S(XY) = 7,451.22

$(SX)^2 = 29{,}608.08 \qquad (SY)^2 = 541{,}225.06 \qquad SX\ SY = 126{,}588.46$

$$^{r}XY = \frac{NS(XY) - SX.SY}{\sqrt{[NS(X)^2 - (SX)^2]\ [NS(Y)^2 - (SY)^2]}}$$

$$= \frac{16 \times 7{,}451.22 - 126{,}588.46}{\sqrt{(16 \times 2{,}220.54 - 29{,}608.08)\ (16 \times 48{,}308.33 - 541{,}225.06)}}$$

$$= -\ 0.19$$

Conclusion—

The negative correlation is clearly not significant.