The Relation Between Soil Moisture and Incidence of Disease in Cacao

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ABSTRACT

The soil moisture status at a cacao estate in Trinidad, W. I., has been estimated by a climatological method for six years. A relation ($r = -0.76^{**}$) between the logarithm of the monthly number of diseased pods and the moisture deficit in the fourth preceding month has been demonstrated. Such a relation could be the basis for predicting disease outbreaks and taking remedial action.

1. Introduction

Very little work has been done on the relation between soil moisture (as distinct from rainfall) and the diseases of crops. This is particularly true of tropical crops. In Trinidad, the two principal diseases of cacao are "Black Pod" and "Witches Broom." Both are due to fungi: *Phytophthora palmivora* Butl. and *Marasmius pernicius* Stahel.

Little is known about the life-cycle of these fungi. They are found either in the pods themselves, or on pods lying on the ground. It is believed that at least part of the life-cycle is spent actually in the soil. Infection of pods by *phytophthora* from soil as deep as 1 meter below the surface has been reported by Orellana (1954). Discussions following papers presented at the Cacao Conference held in London in 1957 also indicate that disease-causing organisms spread from the soil. Even fifty years ago, Hart (1911) mentioned the part played by the soil in cacao disease.

Thorold (1952) investigated the relation between cacao disease and rainfall and humidity conditions in

Africa. In Trinidad, humidity is fairly high throughout the year, as shown in Table 1.

It should therefore be more profitable to investigate the way in which disease depends on soil moisture, rather than on rainfall. Rainfall, *as such*, can have little effect on the fungi. It is only the environment around the disease-causing organisms which can effect their growth. Humidity and soil moisture are the most likely factors, depending on whether the fungus is in or on the ground or on the vegetation.

2. The estimation of soil moisture

Gravimetric measurements of soil moisture (which, if sufficiently numerous, are probably the most accurate) are difficult and expensive to obtain over a period of years. Consequently, it was necessary to use an indirect method. This has been described fully in an earlier paper (Smith, 1959). However, the method will be summarized here.

Certain simplifying assumptions are first made:

- The rooting zone, from which the plants draw their water, remains constant in depth.
- All the rain which falls is assumed to enter the soil, and to remain in the rooting zone, unless the soil is at or above field capacity.
- If the soil is above field capacity, excess water is assumed to either drain through the rooting zone or run off the surface. This occurs by the beginning of the following day.
- The ratio actual to potential evapotranspiration (here called F) is unity at field capacity and zero at wilting point. Between these two values, it is assumed to vary linearly with soil moisture deficit¹.
- The soil surface (as viewed from the air) is completely covered with vegetation.

¹ Soil moisture deficit: The amount of water, usually in millimeters, needed to bring the soil in the rooting zone up to field capacity.

TABLE 1. Relative humidity conditions in Trinidad (34-yr means).*

	0800 hr	1600 hr	Minimum
January	84	68	59
February	81	67	55
March	75	62	53
April	74	63	54
May	76	66	58
June	81	73	60
July	84	74	65
August	85	76	65
September	85	76	64
October	84	76	64
November	85	76	65
December	85	74	63

* The humidity nearly always rises to 100 per cent at night, throughout the year.

- f) The potential evapotranspiration can be estimated by climatological means (in this case, by Thornthwaite's method).
- g) At some point, the moisture deficit is known. This is often the case after heavy rain, when the deficit may be assumed zero. Alternatively, it may be measured gravimetrically.

For the justification of assumption (d), reference should be made to the original paper (Smith, 1959).

It can be shown by simple algebra that the relation between soil moisture deficit and soil moisture (as percentage dry weight) is:

$$D = AX(Y - S) \times 10^{-2}, \quad (1)$$

where A = Apparent specific gravity (volume weight), X = Rooting zone (in mm), Y = Field capacity (percentage dry weight), D = Moisture deficit at soil moisture S (percentage dry weight). If Z = Soil moisture at wilting point (percentage dry weight), (1) becomes

$$D = AX(Y - Z) \times 10^{-2}. \quad (2)$$

when $S = Y$, and the soil is at field capacity, we have, from Eq (1),

$$D = 0. \quad (3)$$

All the terms in Eq (2) are capable of being measured with fair accuracy. They are, to a first approximation, constants. By assumption (d), the curve connecting the F ratio with soil moisture deficit can be constructed for any soil, since when $D = 0$, $F = 1$ and when $D = AX(Y - Z) \times 10^{-2}$, $F = 0$. Only two points are needed to define a straight line.

In Fig. 1, the curve for the soil to be considered is drawn.

3. Illustration of the method of estimation

On a blank sheet, prepared as in Table 2, are entered daily (calculated) values of potential evapotranspiration and of rainfall (in mm). Hypothetical figures are given to show the method of working.

TABLE 2. Specimen calculation of soil moisture deficits.

(1) Date	(2) P.E. (calculated)	(3) Initial deficit	(4) F -factor	(5) Estimated actual transpiration	(6) Rain	(7) Final deficit
Jan.						
1	4.2				48.4	0
2	4.5	0	1.00	4.5	0	4.5
3	4.1	4.5	0.97	4.0	0	8.5
4	4.0	5.4	0.97	3.9	3.1	9.3
5	3.9	-3.0	1.00	3.9	12.3	0.9
6	4.4	-19.7	1.00	4.4	25.0	0

(All figures are in millimeters.)

FIG. 1. The relation between soil moisture deficit and the ratio actual/potential evapotranspiration (F) for River Estate Trinidad, W. I.

On Day 1, because there has been a large amount of rain, we assume that the soil is at field capacity. The moisture deficit is thus zero. This is entered in Column 7.

On Day 2, any rain falling is subtracted from the "Final deficit," column of the previous day, and entered in column 3 as the "Initial deficit." In this special case, both values are zero, and the initial deficit is also zero.

From the F -curve, the value of F corresponding to this value of the moisture deficit is found. This value is entered in column 4. Again, we have the special case of $F = 1$. Columns 2 and 4 are then multiplied together, to give the estimated actual evapotranspiration in column 5. Columns 5 and 3 are added, and the sum put in column 7 as the final deficit for the day.

This procedure is repeated on Day 3. The initial deficit is now 4.5 mm, and the corresponding value of F (from the graph) is 0.97. This gives an estimated "actual" evapotranspiration of $4.1 \times 0.97 = 4.0$ mm. The final deficit is then 8.5 mm.

On Day 4 there was 3.1 mm of rain. The initial deficit is the final deficit of the day before, less this 3.1 mm, i.e., $8.5 - 3.1 = 5.4$ mm. The value of F is again about 0.97, and the final deficit is $5.4 + (0.97 \times 4.0) = 9.3$ mm.

On Day 5, there was 12.3 mm of rain. This means, following the same rules as before, that the initial deficit is $9.3 - 12.3 = -3.0$ mm. The negative sign means that there was a *surplus* of water. It is assumed, however, that this is still retained in the soil (but for Day 5 only). It is therefore available for use by the plants. If the deficit is zero or negative, $F = 1$, and the actual evapotranspiration is 3.9 mm. Following the same rules, columns 3 and 5 are added *algebraically*, giving a final deficit of 0.9 mm.

On the last day, so much rain has fallen that, even when columns 3 and 5 are added algebraically, the result

is still negative ($4.4 - 19.7 = -15.3$ mm). The final deficit is zero, and 15.3 mm of water either drains away or is lost by run-off before it can enter the soil.

This process can be repeated indefinitely. The estimates, under Trinidad conditions, compare well with values obtained gravimetrically (Smith, 1959).

By adding successive moisture deficits, daily, weekly or monthly, one may compute quantities which have been termed moisture-deficit-days (weeks or months). This represents an integration of moisture status with time. It is analogous to the familiar "day-degrees." In this paper moisture deficits were calculated weekly, and "moisture-deficit-weeks" have been used. This has been abbreviated in places to "MDW." By dividing by the appropriate number of weeks, the mean moisture deficit over that period is obtained.

4. Experimental

On an experimental cacao estate ("River Estate") at Diego Martin, Trinidad, detailed records of yields have been kept for some years. In one experiment ("Experiment 1"), records of monthly pod numbers (both diseased and healthy) were available from 1952 onwards. However, cacao takes several years to come into full bearing, and only figures from 1955 were used.

In Table 3, the monthly counts of diseased pods are given from this experiment, and in Table 4 the number of diseased pods as a percentage of the total number harvested (i.e., "diseased" plus "healthy"). These figures are for the whole area of the experiment—about 11 acres.

It may be seen that losses from disease amount to as much as 43 per cent—though this extreme value was in a low-yielding month. Even at the height of the season, however, as much as 32 per cent of the crop is lost.

To some extent, the two fungi can be controlled by spraying. This is normally done on a three-to-four weekly schedule in commercial practice, for eight or nine months of the year. This is a somewhat "hit-or-miss" method. If some means could be devised for forecasting an outbreak, control measures could be taken in time and unnecessary spraying eliminated.

5. The correlation of soil moisture with disease

The soil moisture deficit for River Estate was estimated by the method given in Section 2, for the years 1955–60. The result of doing this is shown in Fig. 2. It may be seen that there are considerable fluctuations, corresponding to a dry season from January to May, and a wet season for the rest of the year.

Cacao pods take about $4\frac{1}{2}$ months to mature, so that any factor which will disease a healthy pod would be expected to operate in this time. (It should perhaps be noted that diseased pods were left on the trees until it was judged that they would, if healthy, have been harvested.)

FIG. 2. Estimated soil moisture deficit for 1955–60, River Estate Trinidad, W. I.

FIG. 3. The relation between monthly number of diseased cacao pods and moisture-deficit-weeks in the fourth preceding month.

TABLE 3. Number of diseased cacao pods harvested per 11 acres.

Year	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
1955	—	—	—	—	557	1213	518	146	47	20	14	9
55-56	3	16	48	677	2422	1093	491	285	188	38	10	1
56-57	34	111	257	1414	390	484	598	252	47	38	12	8
57-58	4	57	196	426	482	199	1004	388	140	19	41	42
58-59	5	374	171	410	1004	929	213	163	48	18	21	14
59-60	10	0	123	486	2266	1746	608	789	495	33	2	2

TABLE 4. Number of diseased cacao pods as percentage of total pods harvested.

Year	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.
1955	—	—	—	—	27	17	5	2	1	1	0	2
55-56	5	26	40	38	20	11	9	10	10	2	1	0
56-57	8	25	8	28	7	10	12	5	1	1	4	10
57-58	11	35	11	14	8	4	25	8	5	1	11	7
58-59	16	43	12	19	10	8	5	8	1	0	1	16
59-60	40	—	19	29	32	13	7	23	12	1	0	0

TABLE 5. Correlation coefficients between $\log_{10}$ (monthly no. of diseased pods) and moisture-deficit-weeks for various periods before counts.

(3)†	(4)	(5)	(3+4)	(4+5)	(3+4+5)	(2+3+4)	(4+5+6)
-0.70**	-0.76**	-0.69**	-0.77**	-0.75**	-0.80**	-0.66**	-0.68**

† (3), (3+4), etc. indicate the MDW in the third month preceding counting, the third and fourth months preceding counting, etc.

FIG. 4. The relation between logarithm (monthly number of diseased cacao pods) and moisture-deficit-weeks in the fourth preceding month.

Correlations were therefore sought between the monthly number of diseased pods and the moisture-deficient-week factor for the month preceding harvesting, the second preceding month, the first and second preceding months, etc. Correlation coefficients were not very high.

When the individual figures were plotted, curves similar to that in Fig. 3 were obtained. It is obvious that any relation is non-linear.

However, if the logarithms of the number of diseased pods were taken, much better correlation coefficients were obtained. Table 5 shows some of the higher values.

All these coefficients are significant at the 1 per cent level. There are no statistically significant differences between them. The result of plotting the logarithms of numbers of diseased pods against the moisture-deficient-week factor in the fourth preceding month is shown in Fig. 4. Also plotted are the 1 per cent confidence limits.

After this figure had been drawn, a few more values became available for 1961. These have been inserted (as open circles). It may be seen that they fit the curve reasonably well.

6. Conclusions

By keeping a log of soil moisture deficits, estimated by climatological means, it has proved possible to predict outbreaks of the two diseases of cacao, and hence of diseased pods. The prediction can be made four months before the outbreak is due to occur, thus giving plenty of time for action to be taken to minimize loss of crops.

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