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THE INFLUENCE OF RAINFALL ON THE COTTON CROP AT KOILPATTI*

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Introductory. The subject of the weather and the crop is receiving considerable attention in these days, and many aspects relating to this problem were discussed more or less fully at the last Conference of Empire Meteorologists in London. While expressing the desirability of accumulating more data on the subject, it was resolved to examine all present records by Dr. R. A. Fisher's[1] method as a first step in the statistical investigation of the problem. The following is an analysis of the rainfall and the yields of the cotton crop at Koilpatti by that method, from data kindly supplied to me by Mr. V. Ramanatha Ayyar, Cotton Specialist, Coimbatore.

Material. This comprises the yields of the past 21 years on the black soil at the Agricultural Research Station, Koilpatti, of Karunganni cotton after fodder cholam and after fodder cumbu. The yields are the averages of the weighed figures of about 20 acres for the several years at that farm, where the rainfall was also recorded. It may not be out of the place to mention at the outset, that from fundamental considerations relating to the theory of random errors in the value of the multiple correlation co-efficient emphasised by Fisher, even 20 years are not enough to gauge completely, the influences of the weather elements and the crop. It has been therefore decided to postpone for the present, the discussion on the true nature of the basic changes in the weather, as also of the crop, until more years of data are accumulated. The relationships of the rainfall to the yield only are presented in this paper, in so far as they are statistically significant from the twenty-one years of data available.

'Trend' influence on yield. Besides the local influences of whether meteorological or otherwise of each particular year, the yields of crops are subject to a long time or 'trend' influence, and exhibit a certain periodicity in their movements, which are to some extent determined by the position of the year in the time, series. These slow changes are the result of a number of unknown causes, independent of the weather elements of each year, but their course is best expressed as shown by Fisher,[2] by a smooth polynomial curve of time. Such a curve of the 5th degree for the cotton crop at Koilpatti is presented in Fig. I., where, reckoning (t) from the middle of the series of years examined, the course of the yield (y) in pounds per acre, can be expressed by the following equations:

$$Y \text{ (after cumbu)} = 377{\cdot}599 - 15{\cdot}872t + 1{\cdot}635t^2 + 1{\cdot}146t^3 - 0{\cdot}0264t^4 - 0{\cdot}01175t^5.$$

$$Y \text{ (after nathu)} = 332{\cdot}517 - 5{\cdot}154t + 0{\cdot}0484t^2 + 0{\cdot}5377t^4 - 0{\cdot}0107t, - 0{\cdot}00625t^5.$$

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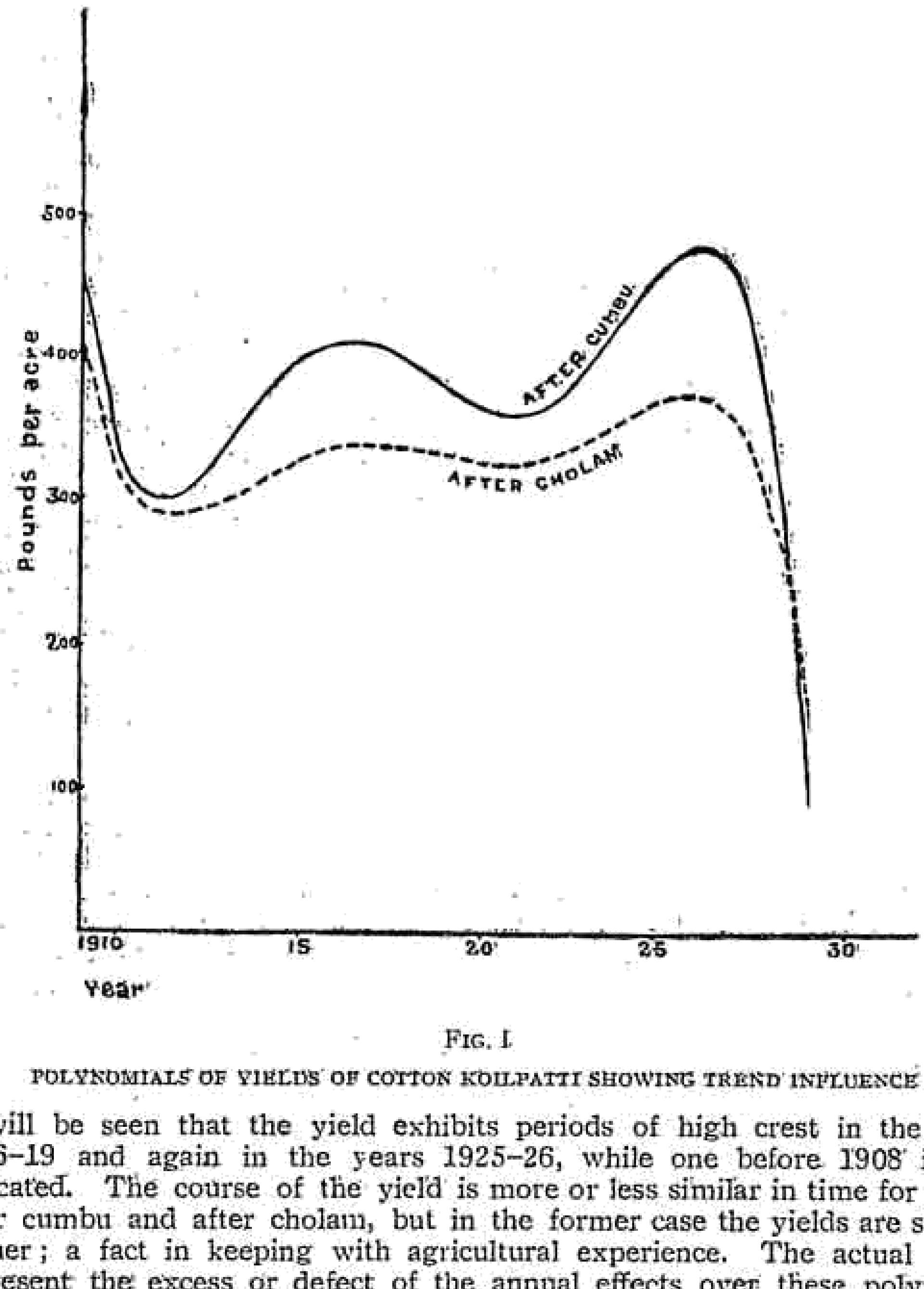

Fig. I

POLYNOMIALS OF YIELDS OF COTTON KOILPATTI SHOWING TREND INFLUENCE

It will be seen that the yield exhibits periods of high crest in the years 1916–19 and again in the years 1925–26, while one before 1908 is also indicated. The course of the yield is more or less similar in time for cotton after cumbu and after cholam, but in the former case the yields are slightly higher; a fact in keeping with agricultural experience. The actual yields represent the excess or defect of the annual effects over these polynomial figures. Much of the variance in yield, can be traced to this 'trend' influence (Table I), but, the effect is exaggerated due to the limited years of data, and require some more study for complete statistical estimation. It is however worthy of note, that the cotton crop at Koilpatti is passing through a period of depression in yield, in the past few years, from which it will take some time to recover.

In judging the effect of rainfall on the yield, we have to eliminate from it the effect of these slow changes, which take place independently of the weather elements. This is mathematically done by fitting the yields biorthogonally to a polynomial of time and correlating the deviations of the actual values from the polynomial fitted.

The distribution of rainfall in relation to yield

In correlating the yield with the rainfall, it is essential to present the effect not only of the quantity of rainfall, but also of its distribution. It is a well known fact that the rainfall at different periods of the year, have different effects on the crop, and also that the same quantity of rainfall precipitating itself on a single day, will have an effect different from that which it will have, when it is distributed over a number of days. In judging therefore, the effect of rainfall, what is most important to consider, is the distribution of rain. To give effective representation to this, the rainfall of each year is fitted to a curve, and the values corresponding to the moments of these curves (given in Table I) are correlated with the yield.

The regression integral. For the above purpose the year is divided into several periods of rainfall. The yield (y) can then be expressed by the ordinary regression method by an equation of the form.

$$Y = a + b_1 r_1 + b_2 r_2 \quad .. \quad .. \quad + b_n r_n \quad ... \quad (I)$$

where $r_1, r_2, .. r_n$ are the rainfall in inches of the 'n' subdivisions of the year and $b_1, b_2 .. b_n$ are the effects, positive or negative, of each inch of rainfall in pounds per acre on the yield. These latter values are the partial regression co-efficients. As 'n' is increased the labour involved in their computation becomes insurmountable. To overcome this difficulty, Fisher has introduced the conception of a regression integral which has the advantage in addition, of fully expressing a fundamental point in the nature of the rainfall influence given below.

The continuity of rainfall effect. An all important factor to consider in the rainfall influence, is that it is a continuous process which takes place throughout the year. Part of the changes are induced in the soil long before the crop is sown, and the total of these slowly varying influences is expressed progressively through different channels on the final yield. It is essential, therefore, that the influences of neighbouring periods are alike. For this purpose the year is divided into small periods. Equation I then takes the regression integral form $\overline{Y} = a + \int_0^t brdt$; where rdt is the rainfall, falling in the element of time dt.

If the rate of rainfall at any epoch is also expressed in the form $r = P_0 T_0 + P_1 T_1 + P_s T_s$.

where $T_0, T_1 .. T_s$ are chosen biorthogonally and $P_s = \int_0 rT_s dt$, the regression of rainfall on the yield can be expressed by the form

$$a = L_0 T_0 + ... L_1 T_1 \quad .. \quad .. \quad + L_s T_s,$$

where $L_s = \int_0^t bT_s dt$.

By this method of Fisher, the number of independent variables Y is reduced to the degree of the polynomial to which the rainfall has been fitted, while the actual distribution of rainfall is more effectively represented. It is possible from this, to express the effect of every additional inch of rainfall in pounds

Table I

Year	Rainfall distribution values—Koilpatti (April to March)						Deviation from polynomial of yield	
	a′	b′	c′	d′	e′	f′	After Cumbu	After Cholam
1908–9	1·07958	−0·14639	−0·12297	−0·08769	0·08433	·01503	24	25
10	1·10375	−0·13262	−0·15240	−0·15697	0·17149	−0·07774	−36	−17
11	1·17333	−0·16064	−0·20478	−0·13154	0·16656	·00062	−21	−31
12	1·28167	−0·13256	−0·22118	−0·11346	0·06488	·11216	22	−43
13	1·29625	−0·17565	−0·42355	−0·30695	0·00961	·02119	7	25
14	1·17667	0·04710	−0·21454	−0·20860	0·11502	·10898	74	99
15	1·53792	0·04155	−0·26033	−0·25350	0·17711	·06801	−56	−47
16	1·59458	−0·07809	−0·24557	−0·25164	0·10436	·17475	18	120
17	·70542	0·00038	−0·06116	−0·01992	−0·00712	−0·11862	−7	108
18	1·44750	0·15647	−0·21363	−0·15858	−0·04640	−0·26661	−126	−79
19	·99958	0·16541	−0·15697	−0·13494	0·08104	·13749	93	7
20	1·21958	·15621	−0·19793	−0·13504	−0·01614	·06341	−34	−15
21	1·47292	−0·02065	−0·15559	−0·28940	0·10348	·10627	58	81
22	1·52542	0·01369	−0·31687	−0·27971	0·22647	·05065	58	13
23	2·06625	0·21395	−0·51339	−0·32865	0·24921	·19869	−98	−104
24	·98500	0·19403	−0·16445	−0·16792	0·05808	·12223	128	111
25	1·53333	0·14430	−0·21428	+0·01140	0·11612	−0·01824	−127	−9
26	1·34792	0·20085	−0·35167	−0·24175	0·05993	·14807	−82	−37
27	1·02667	0·14927	+0·02283	+0·04312	0·07092	−0·03245	143	−20
28	1·53708	−0·29252	+0·09052	−0·23342	0·07036	·07810	−24	11
1928–29	1·21542	0·09225	−0·19875	−0·17920	0·08328	·08085	−14	6
						Variance ...	114302	81172 S $(Y-Yp)^2$
					Total	Variance ...	249285	138520 S $(y)^2$

per acre on the cotton crop at the different periods of the year, as a continuous curve. (Fig. II).

The regressions of rainfall on yield. The actual values of the rainfall distributions corresponding to the moments of the several powers of 't' are given below.

The deviations from the polynomials of yield (given in columns 7 and 8 of table I) are correlated with the rainfall distribution values, giving the sums of products $a'y$, $b'y$, ... $f'y$. These sums of products are multiplied by the corresponding row or column of a matrix of multipliers formed from a determinant of the values a' . . f', and given below (Table II) to give regressions of the yield on the time variate considered.

TABLE II

Rainfall matrix

	a′	b′	c′	d′	e′	f′
a′.	1·55817	−0·00736	−1·38525	2·92315	−2·53466	0·20116.
b′.	−0·00736	1·29059	−0·09359	0·15307	−0·47653	−0·13989
c′.	−1·38525	−0·09357	3·77445	−4·62783	3·53674	−0·52625
d′.	2·92315	0·15307	−4·62783	10·14972	−2·43233	1·72667
e′.	−2·53466	−0·47653	3·53674	−2·43233	13·52150	−1·94559
f′.	0·20116	−0·13989	−0·52625	1·72667	−1·94559	5·59604

The regressions of the rainfall on yield for the several powers of T are given below.

TABLE III

Regressions of rainfall on the yield of cotton

	a′	b′	c′	d′	e′	f′
After cholam	−113·988	−45·425	119·742	−236·772	42·916	275·576
After cumbu.	−457·446	−35·584	635·437	−896·108	965·457	167·509

From these, the effect of every additional inch of rainfall in pounds per acre on the cotton crop for the several fortnights of the year is presented in the form of a smooth polynomial curve in Figure II, the co-efficient of the term relating to $t^{s'}$ being obtained by multiplying the corresponding regression by factors of the form, $\frac{(2s)!}{(S!)^2\, n.\,(n+1)\, .\, .\, .\, .(n+s)}$ where 'n' is the number of subdivisions of the year.

The effect of rainfall. From an examination of Figure II, it will be seen that the effect of every additional inch of rainfall over the polynomial normal is negative almost throughout the year. This negative influence is most pronounced in July to August before sowing, and least in the months of January and February during the growth of the crop. In fact, it is most in the less rainy months. In regard to the calendar year, the effect in direction is more or less similar whether after cotton or cumbu, but after cumbu it is very much greater.

The significance of the rainfall effect. The extent to which the rainfall as judged by its distribution in the several fortnights of the year influences the yield, can be understood by the values of the multiple correlation 'R' given below, with the probability 'P' of such a value occurring due to chance alone.

Cotton		Value of R.	P	Percentage effect of rainfall
After cumbu	...	·829	0·006	55
After cholam	...	·440	·6	not significant

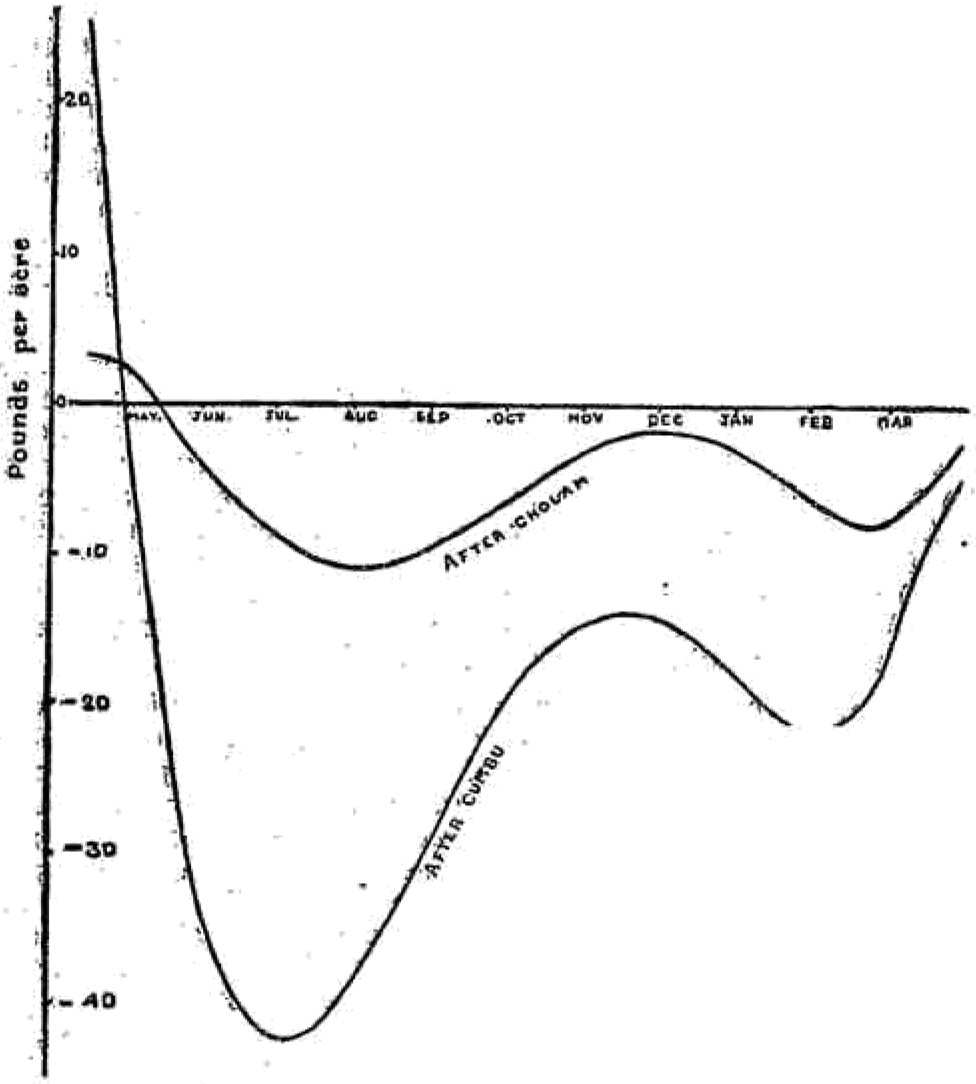

FIG. II

AVERAGE EFFECT IN POUNDS PER ACRE OF EVERY ADDITIONAL INCH OF RAIN ON THE COTTON CROP AT KOILPATTI AT DIFFERENT PERIODS OF THE YEAR

The effect on cotton after cumbu is clearly siginificant, although the percentage of variance attributable to it (55 per cent) is probably exaggerated due to the limited number of years of data. The effect after the cholam is not significant. It can therefore, be inferred that extra rainfall exercises a depressing influence on yield after cumbu in the direction indicated by Figure II, at the different periods of the year. The result is in agreement with the experience at Koilpatti that cotton after cholam withstands the adverse effect of rain better than after cumbu. It is not possible at the present stage to offer any explanation to the above effects noted, although in England, a similar influence on the wheat crop has been associated definitely with washing away of nitrates. Hindrance to the development and aeration of roots is also another possible cause. Before concluding it may not be out of place to mention the importance of another factor affecting the yield.

Effect of the time of sowing. By Fisher's method the influence of rainfall has been computed in relation to the calendar year. In the case of the cotton crop, this relationship is to some extent interfered with by the changes in the date of sowing, brought about by the chance circumstance of the rainfall incidence. An estimate of the rainfall effect in relation to the age of the crop has been made by Mr. V. Ramanatha Ayyar,[3] who has studied the effect of every inch of rain at the different fortnights after sowing. The regression equation for yield in terms of the rainfall for cotton after cholam at Koilpatti is as follows :

$$y : 297 \cdot 6 - 4 \cdot 15x_1 + 6 \cdot 405x_2 - 8 \cdot 824x_3 + 23 \cdot 356x_4 + 6 \cdot 685x_5 + 3 \cdot 373x_6 - 25 \cdot 574x_7 + 18 \cdot 902x_8 + 1 \cdot 145x_9 + 32 \cdot 326x_{10}$$

The effects of the 4th, 8th and 10th fortnights after sowing are very pronouncedly positive, while the 7th fortnight shows a negative effect. Due to the limited degrees of freedom of the data, the multiple correlation (0·74) is not significant (p : 0·3), but the form of the equation suggests the importance of the factor. It might also be mentioned that in experiments conducted at the Cotton Breeding Station early sowing has a most pronounced increased effect on the yield of irrigated cotton, and it has sometimes been observed that in dry cotton also late sown plants fare poorly. Efforts are therefore being made to treat the date of sowing as a dimensional factor affecting the yield in the manner indicated by Fisher.

Summary. The effect of every inch of additional rainfall in pounds per acre on the cotton crop at Koilpatti has been presented for the several fortnights of the year in the form of a smooth curve by the method of Dr. R. A. Fisher. It is found that extra rain has a negative influence on the yield almost throughout the year. This effect is more pronounced in cotton after cumbu, than after cholam. The greatest effect is seen in the dry months of July and August before sowing, and the least in the months of January and February when the crop is on. In the former case, every additional inch depresses the yield by as much as 30 to 40 lbs. per acre, in the case of cotton after cumbu ; after cholam the effect is not significant.

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