Influence of rainfall, humidity, sunshine, maximum and minimum temperatures on the yield of cotton at Coimbatore

8. K. SHAHA and J. R. BANERJEE

Meteorological Office, Poona
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ABSTRACT. The statistical technique of Fisher (1924) was used to examine the influence of meteorological parameters on the yield of cotton crop at Coimbatore. It was observed that the rainfall and hours of sunshine should be more than their normal values for a good crop. More humidity during elongation and branching of the crop is useful for more yield. A lower minimum temperature during sowing period and high maximum and minimum temperatures during flowering are attributed to be beneficial for a better cotton crop.

1. Introduction

For examining the influence of rainfall on the yield of wheat at Rothamsted, Fisher (1924) developed a new statistical technique which takes into account not only the total amount of the rainfall during certain period but also the manner in which it is distributed over the period under consideration. He used this technique to find out the response curve which gives the average change in the yield of wheat associated with an additional unit of rainfall at any time of the year. Kalamkar and Satakopan (1940) used the above method to study the effect of rainfall on the yield of cotton at Government Experimental Farms in Akola and Jalgaon. Nair and Bose (1945) used the same technique to estimate the yield of cotton at Sarakand (Sind) taking the combined effect of humidity and temperature. Acharya et al. (1960) examined the influence of rainfall on the yield of sugarcane at Pusa. Gangopadhyaya and Sarker (1965) employed the same technique to study the effect of rainfall on the yield of wheat at five important crop-weather stations of India. Same method has been used in the present study also to examine the effects of rainfall, sunshine, humidity, maximum and minimum temperatures on the yield of cotton at Coimbatore (Lat. 11°00’N, Long. 77°00’E).

2. Technique

If the time period (0, T) over which the influence of the meteorological factor r is required to be examined, be divided into n equal parts then the linear regression equation of the yield upon the meteorological factor would be of the form:

\[ Y = C + a_1 r_1 + a_2 r_2 + \ldots + a_n r_n \]  

where \( r_1, r_2, \ldots, r_n \) are the quantities of the meteorological factor in the successive intervals of time and \( a_1, a_2, \ldots, a_n \) are the corresponding partial regression coefficients. In the limiting case when the length of the subdivisions is made infinitely small, the Eqn. (1) assumes the form,

\[ Y = C + \int_0^T a \, r \, dt \]  

(2)

where \( r \, dt \) is the amount of the meteorological factor in the infinitely small interval of time \( dt \). \( a \) in the Eqn. (2) is a continuous function of time and represents the average benefit to the crop corresponding to an additional unit of the meteorological factor at any point of time during the period under consideration. This function is known as the regression function and the graph of it is popularly known as Fisher’s Response Curve.

Now if \( P_0, P_1, P_2, \ldots, \) etc be a set of polynomial function of time orthonormal in the interval \( (0, T) \), i.e.,

\[ \int_0^T P_l P_m \, dt = 0 \quad (l \neq m) \]

\[ \int_0^T P_m^2 \, dt = 1 \]

where \( l \) and \( m \) are any two positive integers, the meteorological factor \( r \) can always be expressed as:

\[ r = A_0 P_0 + A_1 P_1 + \ldots + A_{n-1} P_{n-1} \]  

(3)

where the coefficients \( A_0, A_1, \ldots, \) etc are called the Meteorological Distribution Constants. Also, as there are relatively slow changes in the function \( a \) it can satisfactorily be represented
INFLUENCE OF MET. PARAMETERS ON YIELD OF COTTON

As no correlational work is reliable if the variable are having any progressive changes, the yield as well as each of the distribution constants should be subjected to an examination of the slow changes before making any correlational work. For this, the sequence of yields is taken and an orthogonal polynomial of the form:

\[ Y = X_1' P_0 + X_2' P_1 + \ldots + X_6' P_6 \]

is fitted. The square of the ratio of each of the coefficients \( X_2', X_3', \ldots, X_6' \) to the standard residue (S.R.) where,

\[ S. R. = \sqrt{\frac{\text{Residual sum of squares}}{n-6}} \]

is \( F \)-distributed with 1 and \( n-6 \) degrees of freedom. Testing the significance of these \( F \)-values, the slow changes, if any, will easily be revealed. Same procedure is adopted for each of distribution constants. If yield or any of the distribution constants indicates the existence of any slow change then all of them are first corrected for these changes and then only the correlation work is carried out.

Eqn. (5) will then take the form:

\[ Y' = B_0 A_0' + B_1 A_1' + \ldots + B_6 A_6' \quad (6) \]

where \( Y', A_0', A_1', \ldots \) etc stand for the departures of the variables from the corresponding polynomial trend values. Eqn. (5) or Eqn. (6) can be used to calculate the estimated values of yield. The multiple correlation coefficient, which can be calculated at this stage, will give an idea of the extent to which the variation in yield is accounted for by the distribution of the meteorological factor in the period \( (0, T) \).

3. Analysis
The technique described above has been used to study the effects of rainfall, humidity, sunshine, maximum and minimum temperatures on the yield of cotton at Coimbatore. Cotton at Coimbatore is sown sometimes between the end of September and the end of October. The elongation starts after about six weeks of sowing and continues for about ten weeks. Branching also starts simultaneously but it continues for about twelve weeks. Flowering starts after about eleven weeks of sowing and continues for three months. Crop is harvested in April or May after about six to seven months of sowing. The length of the period over which the effects of sunshine, humidity, maximum and minimum temperatures are examined is twenty-seven weeks and is taken from the last week of September (week 39) to the last week of March (week 13). The choice of the week 39 as starting point is based upon the assumption that these meteorological factors, much prior to sowing, may

Fig. 1. Curves showing the yield of cotton (kg/ha) with different meteorological parameters

by an orthogonal polynomial of degree five (Fisher 1924). Let,

\[ a = B_0 P_0 + B_1 P_1 + \ldots + B_6 P_6 \quad (4) \]

Combining the Eqns. (1), (2) and (3) and using the properties of the orthonormal polynomials, we have

\[ Y = B_0 A_0 + B_1 A_1 + \ldots + B_6 A_6 \quad (5) \]

which holds good in the period \((0, T)\).

The Meteorological Distribution Constants can be obtained for each year by fitting an orthogonal polynomial of 5th degree in time to the discrete values of \( r, \bar{r}, r_1, r_2, \ldots, r_n \) and then correlating them with yield figures, the coefficients \( B_0, B_1, \ldots, B_6 \) can be evaluated. The numerical values of these coefficients when substituted back in Eqn. (4) give the required response curve.
not affect the cotton crop. For rainfall, a period of twenty four weeks, from the beginning of August (week No. 31) to the middle of January (week No. 2) is chosen. The arbitrary choice of week 31 as the starting point is made in order to consider the effect of rainfall prior to sowing. The rain beyond the middle of January to the end of March has been left out of consideration as practically there is no rain during this period.

The length of the subdivisions is a week in all the cases. In case of rainfall weekly totals have been used. In case of sunshine, maximum and minimum temperatures weekly means have been used. In case of humidity averages of the weekly means of morning and evening relative humidity percentages have been taken.

The length of the data used is seventeen years and the variety of cotton sown is \( K_2 \). The data before the year 1949 and after the year 1965 have been omitted as different varieties of cotton were sown in those years.

As explained earlier an orthogonal polynomial of 5th degree was fitted to the discrete weekly values of these meteorological factors and the constants \( A_0, A_1, \ldots \), \( A_5 \) were obtained for each year. The orthogonal polynomials used for this purpose were those developed by Esscher (1920) and independently by Fisher (1921). The meteorological distribution constants along with the cotton yields are given in the Table 1 (a) to (c).

For examining the presence of the progressive changes, the coefficients \( X_2', X_3', \ldots \), \( X_6' \) were evaluated for yield and each of the distribution constants as described earlier. These coefficients with the corresponding standard residues are given in Table 3 (a) to (e).

A glance of the Tables 1 and 3 shows the presence of the progressive changes in the yield values as revealed by \( X_2', A_1 \) and \( A_4 \) of rainfall, \( A_6 \) of the maximum temperature and \( A_4 \) and \( A_0 \) of humidity show the existence of some secular changes. But all other constants are free from any significant trend.

The regression planes were then fitted taking yield deviations as the dependent variate and similar deviations of distribution constants as independent variates. These equations with the multiple correlations for each of the five meteorological factors are as follows:

**Humidity**

\[
Y' = 8.119 A_5' + 2.856 A_4' - 6.622 A_3' + 4.846 A_2' + 4.232 A_1' - 1.867 A_0' \\
\text{Multiple correlation} = 0.79190
\]

**Sunshine**

\[
Y' = 16.622 A_5' - 2.438 A_4' - 6.950 A_3' - 2.413 A_2' + 8.168 A_1' - 5.630 A_0' \\
\text{Multiple correlation} = 0.51395
\]

**Maximum temperature**

\[
Y' = 11.062 A_6' + 9.389 A_5' - 20.184 A_4' + 28.719 A_3' + 23.172 A_2' + 5.089 A_1' \\
\text{Multiple correlation} = 0.45628
\]

**Minimum temperature**

\[
Y' = 58.035 A_5' + 107.420 A_4' - 136.919 A_3' - 7.899 A_2' + 33.422 A_1' - 135.062 A_0' \\
\text{Multiple correlation} = 0.84658
\]

Table 2 gives the estimated values of the yield from these regression equations. Significance of the dependence of the cotton yield on the meteorological distribution constants was tested by partitioning the total sum of squares. It was seen (Table 4) that excepting the case of minimum temperature distribution constants, where the ratio of the mean square due to 'regression' to that due to 'residual' approaches the 5 per cent point for this ratio, variance due to regression and the residual does not differ significantly. The percentage of variation in yield accounted for by rainfall, humidity, sunshine, maximum and minimum temperatures are respectively 32.6, 62.7, 26.4, 20.8 and 71.7.

The response curves for each of the meteorological factors are discussed below.

**Rainfall**

The equation of the response curve is:

\[
a = 20.210 P_0 - 25.828 P_1 - 7.028 P_2 - 25.265 P_3 - 16.341 P_4 - 15.941 P_5
\]

and is represented in Fig. 1. From the nature of the curve it appears that upto December end, the rainfall above normal is beneficial to the cotton crop. This satisfies the usual requirement of moisture during germination to reproduction stage (i.e., flowering). After December the rainfall becomes detrimental as rainfall during flowering phase causes flower shedding.
### TABLE 1

Yield (kg/hec) and other meteorological parameters distribution constants

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<tr>
<th>Year</th>
<th>Yield</th>
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<th>$A_2$</th>
<th>$A_3$</th>
<th>$A_4$</th>
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(a) Rainfall distribution constants

(b) Humidity distribution constants

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<th>Year</th>
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(c) Sunshine distribution constants
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### Table 2

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<th>Year</th>
<th>Actual yield</th>
<th>Yield estimated from regression equation</th>
<th>Rainfall</th>
<th>Humidity</th>
<th>Sunshine</th>
<th>Max. temp.</th>
<th>Min. temp.</th>
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<td>269.3</td>
<td>265.6</td>
<td>252.8</td>
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<td>428.1</td>
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<td>439.3</td>
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<td>432.0</td>
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<tr>
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<td>245.1</td>
<td>296.6</td>
<td>281.0</td>
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<td>400.2</td>
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<td>333.4</td>
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<tr>
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## TABLE 3

Secular changes in yield and other meteorological parameter distribution constants

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<th></th>
<th>Mean</th>
<th>$X_1'$</th>
<th>$X_2'$</th>
<th>$X_3'$</th>
<th>$X_4'$</th>
<th>$X_5'$</th>
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<td>Yield</td>
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<td>4.41</td>
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<td>6.54</td>
<td>2.08</td>
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<td>-5.72</td>
<td>-0.37</td>
<td>-2.23</td>
<td>1.18</td>
</tr>
<tr>
<td>$A_3$</td>
<td>5.57</td>
<td>5.04</td>
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<td>0.16</td>
<td>5.12</td>
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<tr>
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<td>-0.27</td>
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<td>-2.38</td>
<td>1.60</td>
<td>5.47</td>
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<tr>
<td>$A_5$</td>
<td>4.30</td>
<td>-2.38</td>
<td>-6.83</td>
<td>-3.12</td>
<td>0.48</td>
<td>5.47</td>
<td>5.47</td>
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<tr>
<td>$A_6$</td>
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<td>-3.05</td>
<td>-7.21</td>
<td>1.23</td>
<td>4.50</td>
<td>2.69</td>
</tr>
</tbody>
</table>

### (a) Rainfall distribution constants

| $A_7$  | 345.66 | 46.91  | 12.03  | 0.04   | -5.76  | 1.37   | 9.04 |
| $A_8$  | -34.18 | 4.25   | 0.81   | 1.12   | 4.25   | -1.44  | 7.11 |
| $A_9$  | -6.23  | 16.33  | -11.23 | -6.10  | 2.31   | 3.84   | 4.56 |
| $A_{10}$ | 9.07   | 7.55   | -2.05  | 6.94   | 3.96   | 5.38   | 5.48 |
| $A_{11}$ | 0.63   | -0.21  | 5.83   | 11.50  | -12.53 | 3.28   | 5.48 |
| $A_{12}$ | 3.06   | -4.08  | 6.08   | 4.00   | 4.37   | 16.94  | 10.83|

### (b) Humidity distribution constants

| $A_{13}$ | 42.03 | 0.87   | 2.74   | 1.71   | -0.19  | 2.24   | 1.95 |
| $A_{14}$ | 5.92  | 1.51   | -1.19  | -1.03  | 1.74   | -1.84  | 1.22 |
| $A_{15}$ | 0.50  | 1.21   | -0.99  | -1.99  | 0.87   | -1.29  | 1.78 |
| $A_{16}$ | 1.58  | -0.73  | -0.52  | 1.44   | -2.02  | 1.49   | 1.45 |
| $A_{17}$ | 0.16  | -0.06  | -0.41  | -0.06  | 2.15   | 1.77   | 1.44 |
| $A_{18}$ | -0.68 | -0.79  | -0.74  | -2.35  | -0.97  | -0.37  | 2.30 |

### (c) Sunshine distribution constants

| $A_{19}$ | 160.58 | -7.19  | 1.77   | 0.86   | -3.59  | 1.36   | 1.96 |
| $A_{20}$ | 6.50   | 0.69   | -1.29  | -0.65  | -0.35  | 0.48   | 0.96 |
| $A_{21}$ | 8.47   | 0.60   | -0.83  | -1.23  | 2.46   | -1.90  | 1.28 |
| $A_{22}$ | -0.40  | -1.15  | -1.17  | -0.14  | -0.13  | 1.11   | 1.11 |
| $A_{23}$ | -1.56  | -0.02  | -0.46  | -0.43  | -0.46  | 0.35   | 0.66 |
| $A_{24}$ | -0.76  | 0.09   | -1.75  | -2.17  | -0.06  | 1.31   | 1.53 |

### (d) Maximum temperature distribution constants

| $A_{25}$ | 102.34 | 4.49   | -5.88  | -0.90  | -2.71  | -0.68  | 2.56 |
| $A_{26}$ | -2.43  | -0.12  | -1.30  | 1.21   | 2.42   | -0.12  | 1.53 |
| $A_{27}$ | -6.25  | -2.10  | 3.04   | 1.84   | -3.34  | 0.65   | 1.74 |
| $A_{28}$ | -2.48  | 0.41   | 2.16   | 0.78   | 1.26   | -1.03  | 1.28 |
| $A_{29}$ | -0.80  | 0.45   | -0.34  | 1.76   | -0.08  | 0.26   | 2.33 |
| $A_{30}$ | 0.29   | -1.43  | -1.45  | 2.33   | 1.19   | 1.16   | 1.94 |

---

### Humidity

The equation of the response curve for humidity is:

\[ a = 8.119 P_0 + 2.856 P_1 - 6.622 P_2 + 4.846 P_3 + 4.232 P_4 - 1.867 P_5 \]

It is represented in Fig. 1. It shows that from the beginning of November which is the period of commencement of elongation and branching, more than normal relative humidity is beneficial to the yield. During the germination period the relative humidity above normal is detrimental to the cotton yield.

### Sunshine

The equation of the response curve is:

\[ a = 16.622 P_0 - 2.488 P_1 - 6.950 P_2 - 2.413 P_3 + 8.168 P_4 - 5.630 P_5 \]

It is also represented in Fig. 1. The curve shows that the sunshine has practically no effect on the cotton crop. However, it will be better if the sunshine is always above the normal.

### Maximum temperature

The equation of the response curve is:

\[ a = 11.062 P_0 + 9.389 P_1 - 20.184 P_2 + 28.719 P_3 + 23.172 P_4 + 5.089 P_5 \]
It is also represented in Fig. 1. The response curve clearly shows that during October which is the sowing period also, a fall in the maximum temperature is beneficial, because at high maximum temperature, germination of seeds are affected adversely. During the elongation and early flowering periods a rise in the maximum temperature is good for the cotton yield. Maximum temperature below the normal during February and March is again beneficial to the yield. This being the peak flowering period, moderate to low temperature facilitates good flowering.

**Minimum temperature**

The equation of the response curve is:

\[ a = -58.035 P_0 + 107.420 P_1 - 136.919 P_2 - 7.899 P_3 + 33.422 P_4 - 135.062 P_5 \]

It is also represented in Fig. 1. From the curve it is evident that up to the middle of November which is the commencement period of elongation and branching in the cotton plants, it is highly beneficial to the crop if the minimum temperature goes down, as average to moderately lower minimum temperatures are required for good growth during the early stages of crop. From the middle of November to the middle of January minimum temperature is beneficial. From middle of January to the middle of February any increase or fall in the minimum temperature does not affect the yield much. After the middle of February again an increase in the minimum temperature is desirable for a good cotton yield.

**4. Conclusion**

The significance of the effects of rainfall, sunshine and maximum temperature could not be established clearly, because of the respective low multiple correlation coefficient. However, it was observed that more sunshine during the crop period and more rainfall up to the middle of January were beneficial to the crop. More relative humidity during the elongation and branching period is useful for the crop. During the elongation, branching and flowering period higher maximum temperature benefits the yield. Minimum temperature plays the most important role in explaining about 72 per cent of the total variation in cotton yield.

### Table 4

**Analysis of variance**

<table>
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<tr>
<th>Factor</th>
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<th>D.F.</th>
<th>M.S.</th>
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<th>F (table)*</th>
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</table>

* F (table) of 5 per cent and 1 per cent

Minimum temperature during the month of sowing and the early stages of elongation and branching of cotton plants should be below normal for a good yield. During the flowering period it should be above normal.

**Acknowledgement**

The authors have great pleasure to record their grateful thanks to the Director of Agricultural Meteorology for facilities to carry out this work. Thanks are also due to the crop weather observers of Coimbatore who have recorded the data made use in this paper.

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