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INFLUENCE OF WEATHER ON CROP YIELDS

A Review of Agro-meteorologists' Research

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Economists' interest in the study of crop-weather relations is of

relatively recent origin and reflects the growing realisation that the

effect of weather needs to be taken out of the observed behaviour of crop

yields before the contribution of technology and inputs can be properly

evaluated. However, their work on the subject shows little awareness of

the research already done by agricultural scientists and agro-meterologists,

or of the painstaking effort which went into the collection of the relevant

basic data. The Seminar on Data Base and Methodology for Study of Growth

Rates in Agriculture, organised und r the auspices of the Indian Society

of Agricultural Economics, suggested that a brief critical review of the

past scientific work on crop-weather relations should be prepared and

published along with the papers discussed at the Seminar. The present review

was prepared in response to this suggestion. It is far from exhaustive:

Much of the work is reported in specialised journals which are not easily

accessible to readers outside the profession. Though limited to a few

papers, it is believed that the review covers a wide enough cross-section

to give the main contours of past research in this field. At the end of

the paper is a bibliography somewhat wider in coverage than the contributions

reviewed but still far from comprehensive.

The subject of crop-weather relations has attracted attention of Indian Scientists for several decades. While some work has been done by agricultural scientists (notable examples being Harold Mann 1955, Kalamkar and Satakopan 1940, and Kanitkar 1960) the main centre of research on crop weather relations during the past half-a-century has been the Indian Meterological Department (IMD). To encourage a proper scientific study of the relation between weather and plants a separate division of Agricultural Meteorology was started in 1932 and its pioneering work has been widely recognised. In its early years the Division was mainly concerned with macro-analysis of distribution and variability of rainfall, and estimation of evaporation and crop-weather requirements as well as with micro studies of climatic variables near the ground to improve understanding of the environment affecting plant growth (Ramdas 1960). In 1945, the ICAR launched an All India Coordinate Crop Weather Scheme (AICWS). Under this scheme specialised meterological observatories were set up for "systematic recording of crop-weather observations on paddy, wheat and jowar, at a net work of selected experimental farms throughout the country". These observatories were later extended to sugar cane and cotton as well. The object of the scheme was to "formulate, in quantitative terms, the effect of different growth factors on the growth and yield of crops under observation...." (Mallik, 1958, p.30).

The All India Crop Weather Scheme

At its peak activity, there were 125 observatories under this scheme, of which 50 centres recorded detailed and systematic observations, on a uniform basis, regarding the growth and yield of selected crops as well as the meterological factors experienced by the crops during its life cycle.

It is useful to know the scope and design behind this endeavour.

"At each station, two varieties of the crop under observation are grown according to the following layout plan, with 6 plots under each variety.

$$V_1 \quad V_2 \quad V_2 \quad V_1 \quad \quad V_1 \quad V_2$$

$$V_1 \quad V_2 \quad V_2 \quad V_1 \quad \quad V_1 \quad V_2$$

V_1 = I Variety

V_2 = II Variety

"The size of the plot is 1/40 acre. The sampling unit is 8 ft length (ultimate units) in adjacent rows. Three such samples are selected by randomization from each half of the plot, giving 36 samples or 72 ultimate units, for each variety. The two end plants of each ultimate unit come under measurement.

"The height measurements are thus made on 144 plants in all, for each variety, selected by randomization. The height is measured from the ground upto the base (juncture) on the topmost fully opened leaf. The height values represent the average of the heights from the ground to juncture of the top most fully opened leaf, based on the measurements made on 144 plants of each variety selected by randomization, at a time when the height of the crop has reached the maximum. The yield values, however, are based on the yield of all the six plots of each variety, pooled together." (Mallik, 1958, p.377).

"The data are tabulated on standard printed forms, according to standard weeks and periods of the "Growers Year". The advantage of using the "Grower Year" is that each standard week of the year covers the same calender dates every year and it is, therefore, convenient to obtain normals for each standard week, when data for a sufficient large number of years are accumulated. The tabulated data are promptly scrutinised at the office of the Director of Agricultural Meterology and care is taken to ensure that the accumulating data remain free of any serious shortcomings.

"After scrutiny, both the meterological and the crop data for each crop, for each year are represented pictorially in crop-weather diagrams.... Such diagrams summarise a wealth of data depicting the life history of the crop from sowing to harvest, indicating the dates of commencement and completion of various growth phases such as germination, tillering, or branching, elongation, flowering and yield " (Mallik, 1958 a, pp 32-37)

One cannot but be impressed by the care and imagination which
evidently went into the design of the crop weather observations. A
large mass of information was collected from the 50 stations for
periods ranging from 5 to 20 years. But, for reasons which are not
very clear, the collation and publication of the data in the
standardised format was rather fitful and incomplete. The crop-weather
scheme in its original form was discontinued from the late sixties.
The present position is explained by Sarkar thus:

> "In the last two decades, large changes have taken place in the
> country in Agricultural Production Technology. Old crop varieties
> and the agricultural operations have also undergone substantial
> changes. To be in tune with and to cater to the need of these new
> developments, the precision crop-observations are being replaced
> by those requiring the recording of simple observations on the
> growth, development and yield of important crop varieties from
> all agro-meterological stations, such that enough data becomes
> available for analysis in a short period of time....The information
> collected from the network of observations is also being mapped
> for issue as an Agro-climatic atlas of India. The crop and meteo-
> rological data under the crop weather scheme are being published
> in the form of crop-weather diagrams, which are a factual summary
> of the week by week progress of the crop growth and the weather
> conditions experienced by it" (Sarkar 1977, p.2)

Precise information on the data collected under the new scheme, the
format of presentation and the nature of the publication are not
available.

Analytical Work on Crop-weather relations

The empirical work on crop-weather relations is largely on the AICWS
data. Reviewing the status of this work, Sarkar reported:

> "Some tentative crop-weather relationships have been established
> with respect to the crops at different crop weather stations by
> applying statistical methods. Response of a few crops in yield to
> distribution of rainfall during the life cycle of the crop has also
> been obtained. Similar studies in relation to other meterological
> parameters like maximum temperature, sunshine and humidity are
> in progress" (Sarkar, 1977, Ibid).

Some of the early attempts at analysing AICWS data used relatively simple techniques to get an idea of yield-weather relations. For instance Mallik (1958) examined 9 years data for three crops at the Dharwar Research Station and found that the two years when the wheat yields were very low due to a rust attack, the number of hours of bright sunshine days during November was abnormally low. From this he concluded that "unseasonal rain and cloudy conditions created conditions favourable for severe rust attacks". On the other hand in jowar, on the basis of a comparison of rainfall during the growing season in two years of very good harvest with that in two years of very poor harvests, he argued that "jowar crop at Dharwar is rather susceptible to excessive rain during the growing period". Using a similar approach it was further suggested that "spell of cloudy and rainy weather extending over 3 consecutive weeks during the growing season of cotton appears to create conditions favourable for pests like shoot borer and red-cotton bug".

In another paper Mallik et al (1958) attempted a more elaborate analysis of 10 years data relating to jowar from 5 stations. They postulated partly for lack of any other basis, that optimum amount and distribution of rainfall during the growing period of kharif jowar, is approximated by the amount of rainfall and its distribution (in each of 12 weeks prior to ear-emergence). They then estimated the correlation coefficients between (a) height and yield; (b) the percentage of the deviation of actual weekly rainfall during the growing period in each year from the rainfall in corresponding weeks of the "optimum" year (i.e. the year of the maximum yield in the sample) and the percentage deviation from the maximum height; and (c) deviation in rainfall from year of optimum yield and deviations

from optimum yield using a similar procedure as in (b). He found the correlation coefficient (a) to be significantly positive (0.59), and (b) and (c) to be significantly negative (0.42 and 0.51 respectively). The correlation coefficient of yield and rainfall on height was also significantly negative (-0.35). Apart from the fact that there is no explicit apriori basis for the relation sought to be estimated, the analysis, as the authors recognise is limited and tentative as it does not consider the effects of other meterological variables or the effects of rainfall and other met factors between ear emergence and harvest, and because it is based on pooling of observations from different stations with varying agro-climatic conditions and possibly different varieties of each crop.

A subsequent paper (Mallik et.al 1960) attempted a rather more elaborate analysis of data for cotton from some 12 stations. Here again, the stations were pooled into two groups (on the basis of rainfall in the reproductive period) to get a sufficient number of observations for studying correlations between (a) different growth features and yield; and (b) meteorological factors and some growth features. In both groups of districts, the selected growth features (germination rates, number and height of plants at first picking, number of branches, total number of flowers and of bolls at first picking) were found to explain more than 92 per cent of the yield variations. Of the meteorological variables, the correlation analysis found that for one group of stations (i) greater rainfall during the four weeks preceeding the branching period, as well as during the period, and more rainy days during branching increased the number of branches; (ii) greater rainfall and more rainy days during boll

formation reduce the number of bolls available per picking; and (iii) higher maximum temperatures during boll formation tend to increase the number of bolls for picking. In the second group of districts the relations are much less clear: Greater sunshine during the four weeks prior to germination seems to increase the germination rate, while more sunshine during boll formation has a marked negative effect on the number of bolls picked.

This kind of analysis which tries to scan the strength and pattern of relations between a variety of met variables which are expected on apriori grounds to affect yield is valuable especially when there is no well-formulated hypothesis on the precise nature of the relationship. The problem posed by pooling of observations could be overcome once sufficient number of observations are available for a particular variety and station. But this approach was apparently not pursued very far. At any rate the next major paper on the subject is already cast in the framework of regression analysis.

The simplest of these estimates a linear regression of yield on the values of selected met variabless during selected "sensitive" periods on the basis br selection of met variables or of the regression(Sreanivasan 1973 The procedure seems to involve screening the relation between weekly rainfall and yield, and choosing those which gave statistically significant correlation coefficients. In order to arrive at the periods of rainfall critical to yield, a further selection is made from among these "by an elimination process and from considerations of crop physiology". The details of the procedure are unfortunately not reported in the paper.

The details are presumably reported in Sreenivasan's Ph.D thesis (1970). Incidentally, for the two stations for which this approach was tried, Sreenivasan reports a multiple correlation coefficient of 0.66-0.68.

In another paper Sreenivasan and Banerjee (1973) present the results of a linear multiple regression of the yield of rabi jowar in Raichur on mean maximum temperature, mean minimum temperature, total rainfall and no. of rainy days. The multiple correlation coefficient is -around 0.54 but no further details (e.g. the statistical significance of the coefficient, or the basis for the model chose) are available.

The paper then goes on to experiment with the "multiple curvilinear regression" technique evolved by Ezekiel and Fox (1965) on the same body observations. The starting point is the linear multiple regression of the standard type.

$$Y = a_1 + a_1X_1 + a_2X_2 + \ldots\ldots\ldots a_nX_n \qquad (1)$$

hile this is a useful first approximation, the relation between Y and each of the independent variables may have different, and not necessarily linear, forms. The true relationship in other words would be of the following form.

$$Y = a_0^1 + a_1^1 f_i(X_1) + a_2^1 f_2(X_2) + \ldots\ldots\ldots + a_n^1 f_n(X_n) \qquad (2)$$

where $f_1(X_1)$ etc may have different forms, not necessarily linear. The nature and shape of $f_i(X_i)$ are got by a process of successive approximation using free-hand curves. The multiple and partial correlation coefficients are then estimated by feeding the free hand approximation of the curvilinear functions into equation (2).

The method is found to explain a much higher proportion of the observed variations in jowar yields in Raichur than the linear regression. But a high R^2 is not a sufficient basis for selecting one "model" over another even when standardised and objective techniques of curve-fitting are available. Such techniques have not been developed for curvilinear regression. Ezekiel and Fox, stressing the limitations of this technique, said:

> "The results of the corn yield analysis apply only to the same area from which the data were drawn and to the period they covered. Thus they provide no basis for estimating corn yield in other seasons, and their use in estimating yield in other periods - as in subsequent year - is attended by increasing risk due especially to the necessity of extrapolating the trend regression...." (pp 240-241).

In any event, unless the underlying model is firmly grounded on theoretically sound and consistent hypotheses derived from the relevant disciplines, its utility for understanding crop-weather relations remains doubtful no matter how high the R^2.

Some attempts have also been made to apply what is called the "regression integral technique" developed by Fisher (1924) for analysing crop-weather relations. An early and frequently cited example of this is the paper by Kalamkar and Satakopan (1940). There were also others e.g. Nair and Bose (1945), Acharya et al (1960) and Gangopadhyay and Sarkar (1965). But none of these was available for reference. The only two papers in this category which the author could get are those of Sreenivasan (1973) and Shaha and Banerjee (1975) who applied the technique to analyse AICS data for cotton in Madhya Pradesh (Indore and Khandwa) and Coimbatore respectively.

The technique is meant to "take into account not only the total amount of rainfall during a certain period but also the manner in which it is distributed over the period under consideration". The basic relation between yield and met factors are cast in the linear form thus:

$$Y = C + a_1 r_1 + a_2 r_2 + \dots \dots \ a_n r_n \qquad (1)$$

When Y stands per yield; $r_1 r_2 \dots r_n$ the values of a meteorological factor r in period n, and the periods represent equal sub-divisions of the total period over which the effect of the met factor is to be studied; and the partial regression coefficients $a_1 a_2$, etc give the responses of r_1, r_2 etc on yield. At the limit, when the duration of 'each time interval is very small, (1) becomes

$$Y = C + \int_o^T ardt \dots \dots \qquad (2)$$

For each met factor r, Meteorological Distribution Constants (MDCs) are "estimated for each year by fitting an orthogonal polynominal of the 5th degree in tune to the values $r_1, r_2 \dots \dots r_n$."

$$r = A_0 P_0 + A_1 P_1 + \dots \dots A_5 P_5 \qquad (3)$$

Yield response to the MDCs ($A_{c1} A_1 \dots$) assumed to take the following poly-nominal form.

$$a = B_0 P_0 + B_1 P_1 + \dots \dots B_5 P_5 \qquad (4)$$

In order to estimate $B_o B_1$, yield is regressed on $A_o, A_1 \dots \dots$;

$$Y B_0 A_0 + B_1 A_1 + \dots \dots + B_5 A_5 \qquad (5)$$

Both papers also examine the data to see whether there is any significant change in yield and/or the MDCs, and describe a procedure for eliminating such trends.

Sreenivasan's paper is concerned with estimating the relationship between the distribution of rainfall and cotton yields in Madhya Pradesh. The partial coefficients for the MDCs differ substantially in strength (though not in sigh) between the two stations studied. The proportion of variance explained by this technique (0.53 to 0.63) is actuall lower than that of the simple linear regression of yield on the values selected met variables in different stages of crop growth (0.66-0.67). Both techniques are reported to do equally well when judged by the closeness of the predicted to the actual yield levels.

Shaha and Banerjee examined the effect of rainfall, humidity, sunshine, maximum and minimum temperatures, each taken separately (and considering the values of each variable over the entire growing season) on cotton yields. Some of the main conclusions of their analysis are: While the significance of the effect of rainfall, sunshine and maximum temperature (on yield) could not be established clearly there is indication that "more sunshine during the crop period and more rainfall upto the middle of January were beneficial; more relative humidity during elongation and branching period is useful for crop"; and "minimum temperature plays the most important role in explaining about 72% of the total variation in cotton yield". (Shaha and Banerjee, 1975 p.524)

It is obviously difficult to judge the effectiveness of the regression integral technique in relation to others on the basis of these two applications. Nevertheless at the conceptual level the major limitations of this method, at any rate as applied so far, is that it estimates the effect of each met factor (and its time distribution) on yield separately, but not in combination. This would require a more complicated model of the relation between yield on the one hand and different met factors and their distributions taken in combination on the other. The simplest would be an additive model i.e., one which postulates the separate effect of each met variable, like those of the values of any particular met factor in different parts of the growing season, are independent of each other. This can of course be questioned. For instance there

is strong reason to believe that the adverse effect of moisture
stress at different stages of crop growth tend to be cumulative
rather than additive (Minhas et al 1974). Thirdly, since the
study is meant to examine the relationship between the two on
the basis of data from experiments specifically designed to
control for all influences on yield other than the met factors,
the rationale for the elimination of trends in met variables
and yields is not clear.

Forecasting Crop Yields on the basis of Weather Parameters

In 1945 the Agro-meteorolgy Division of the IMD started
preparing monthly crop-outlook assessments based on the week-by-
week progress of weather for use of the Ministry of Food and
Agriculture. More recently, efforts are being made to develop
techniques for quantitative crop yield forecasts on the basis
of "long series of past crop yield data and meteorological
parameters". "Regression formula connecting crop yield and
weather parameters in critical crop periods have been developed
to forecast the yields of Kharif Rice in 22 meteorological
sub-divisions and wheat in 9 sub-divisions." (Sarker, 1977,
p.7) We have reviewed two of these studies (Das and Vidhate
1972, and Das et al, 1971) to illustrate the methodology.

The first paper relates to wheat in Uttar Pradesh taken
as a whole. Data relating to average yield per acre and average
rainfall, temperature (maximum, minimum, and mean) and humidity
during the growing season from 1921 to 1966 have been used in the

analysis. The average yield is correlated with the above net variables in different phases of the crop.

> "To get the periods in which meterological factors have a significant effect on yield, the linear correlation between yield and rainfall, temperature and humidity have been worked out for overlapping periods of seven days to ninety days of the crop growing season...... All the correlations have been examined and from them the periods in which a particular weather element is significantly correlated with yield are marked out. By using these factors, the multiple correlation with yield has been calculated. Some of the factors used are not significant at 5% level. In order to find out the combination in which the parameters used are all significant at least 5% level,.... multiple correlation coefficients of all combinations (are calculated) dropping gradually one or more variables till a combination is found out where all parameters used are significant." (Das and Vidhate, 1972, p.3)

All values are averaged for the whole State and no distinction is made between irrigated and unirrigated areas. The increasing trend in yield observed since 1951, being assumed to be due to various development programmes, are sought to be taken into account by introducing "a suitable time scale linear variable in the regression analysis".

The regression which is eventually chosen on the above basis includes seven variables which together "explain about 73 per cent of the observed variance in yield in 1921-65 and 70 per cent in 1951-65. The signs of the coefficients for each variable are the same in both periods, though the magnitudes are different. Predicted yields in 1966-1970 are closer to the expected yields computed from the regression for the longer time series (the difference is within 4 percent) than from the regression for 1950-65 (where the difference is around 10 per cent.

The paper by Das et. al. attempts a similar exercise for kharif paddy in three regions of Mysore based on yield data for periods ranging from 24 years in one region to 53 years in another. Again no distinction is made between yield under irrigated and unirrigated conditions; and while the change in methods of yield estimation of the 1950 are noted, their implications for the comparability of the two series is not considered. As in the study of wheat in UP, a time trend variable is introduced in the region to take out the effect of rising trend in yield after 1950, and the regression is estimated for the longer time series and the post-1950 period separately.

The following is a list of the explanatory variables found to have a significant effect on yield in each region.

Variable No.	Central Mysore	Interior Mysore North	Interior Mysore South
X_2	Restricted rainy Days 1 July - 15 Sept.	Mean May Temp July/Sept.	Sept. Rainfall
X_3	Occasion of doughts and floods in August/ September	X_2^2	June Rainfall
X_4	June rainfall	Occasion of drought and flood in August/September	Occasion of drought in July/August
X_5	Mean Max. Temp. July/August	July rain	Mean Max. Temp. July/August
X_6	X_5^2	Square of July/ August rainfall	X_5^2
X_7		Technological trend	

The Mean maximum temperature in July/August or July/September as well as incidence of drought and floods in August/September figure as significant variables in all regions. With one or two exceptions, the signs of the coefficients are all the same in both the periods, but, unlike in the longer series, a majority of the regression coefficients for the 1950-64 period are statistically non-significant even though the proportion of variance explained by the regions exceed 90 percent. Predicted outputs between 1965 and 1968 based on regression coefficients from the longer series are in general quite close to actual output in coastal Mysore; they do rather less well in the other two regions especially. Interior Mysore South. The predictive power of the regression based on the shorter series is uniformly much poorer, the expected values diverging from the actuals by 10 percent or more in 8 out of 12 cases.

That the models reported in both these papers do so well in predicting the time series of actual yields and also in forecasting the yields for at least a four year period beyond the time span of the series is indeed remarkable. It would be interesting to know whether these type of "models" do as well in other regions for which they have been tried, whether they predict as well the yield of more recent years and whether such work has been extended to other crops.

Be that as it may, this type of approach leaves one rather uneasy from a methodological viewpoint especially when one is

trying to understand the nature of crop-weather relations.

To take but one example. The failure to distinguish yields of irrigated from rainfed land is obviously untenable because the effect of meteorological factors, especially rainfall, is apt to be very different in the two cases. Taking values of meteorological factors as a simple averages of the values observed at the metereological stations is questionable in a state as large and as varied in climatic conditions as UP. So is the highly empirical approach to screening the explanatory variables using R^2 and tests of significance of the coefficients as the basis for selecting the final regression. The introduction of a linear trend variable to eliminate technological trends for a part of the series is highly arbitrary: For instance, both papers _assume_ that the technological improvement and the consequent trend rise in yields is a post-1950 phenomenon. The graphs of the time series for Mysore raises strong doubts about this assumption. It would seen that yields have been on a rising trend from the early forties in Central Mysore and interior Mysore South and from the mid-thirties in Interior Mysore North. And in Central Mysore, the rising trend after early forties was preceded by two decades or more of a secular _decline_ in yields. That these aspects are not taken into consideration in the analysis makes these regression models of limited value as a basis for understanding crop-weather relation

Conclusion

The above review is obviously far from complete in its coverage of the work done at IMD and other scientific bodies on crop weather relations. But in so far as the papers covered form a fairly representative cross-section of the work, we could, at some risk, attempt to summarise the state of knowledge they reflect: It is evident that the AICWS was a well designed enquiry and that it did generate a mass of crop-weather information under controlled conditions for different parts of the country. Unfortunately much of this data remains unpublished, and its quality and utility for analysis of weather-yield relations remains to be properly tested. The analytical work done on this body of data is far too inadequate a basis for evaluating the AICWS. This work opens up interesting possibilities but they need to be tried out on many more stations and crops on the basis of much closer and conscious inter-action with plant scientists to enable formulation of meaningful hypotheses for testing. The forecasting models based on macro data, being highly empirical in their approach, are of doubtful value for understanding weather yield relations; but seem to be quite good for statistical predictions of yield given the values of the net variables. Here again it would be useful to examine (a) the predictive power of these models in the case of other crops and regions for which they have been attempted, as well as (b) the closeness of actual yields to the advance yield forecast reportedly made by the IMD every year for use of the Ministry of Agriculture.

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IJAS -   Indian Journal of Agricultural Sciences

IMD   -   Indian Meteorological Department

ISAE -   Indian Society of Agricultural Economics

IJMG -   Indian Journal of Meteorology and Geophysics