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Evaluation of effect of technology and weather fluctuations on rice yields in Punjab

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सार — उत्पादन प्रागुक्ति तथा सस्य उत्पादन में जलवायु जोखिम तत्व के निर्धारण के लिये विश्वसनीय सस्य मौसम शिल्प-विज्ञान मॉडलों की आवश्यकता है। वर्तमान अध्ययन में पंजाब में खरीफ की धान की फसल के पूर्वानुमान के लिये ऐसा ही एक प्रयास किया गया है। अनेक बहुसमाश्रयणों के सूक्ष्म परीक्षण से पता चला है कि शिल्प-विज्ञान प्रवृति प्राचल तथा समाश्रयण समीकरण के विकास में प्रयुक्त आँकड़े विशिष्ट अवधि के प्रति बहुत संवेदनशील है। इस अध्ययन में तीन शिल्प-विज्ञानी प्रवृति प्राचलों को चालू किया गया है। मौसमी प्राचलों में से जुलाई के दौरान वर्षा को स्थिर उल्लेखनीय प्राचल पाया गया है, जो आँकड़ा प्रयोग करने की अवधि के प्रभाव से मुक्त है।

ABSTRACT. Reliable crop weather technology models are needed for yield prediction and for the determination of climatic risk component in crop production. In the present study such an attempt has been made for forecasting kharif rice yield in Punjab. Critical examination of several multiple regressions showed that the yield is very sensitive to technological trend parameter and to the specified period of data utilised to develop the regression equation. In the study three technological trend parameters have been introduced. Among the weather parameters rainfall during July has been found to be a stable significant parameter independent of the period of data used.

1. Introduction

The impact of weather and climate on crop output and hence on world food supply has generated continuous interest in the watch of crop prospects in different parts of the world. India is one of the major rice producing countries in the world, second only to China (WMO 1977). Paddy is grown mostly during the kharif crop season (*i.e.,* June to October) under widely varying conditions of soil, altitude and climate, from the humid areas in the eastern India to the semi-arid region in the west. Punjab is one of the foremost states where paddy is grown and as a consequence to the introduction of large scale technological inputs in its production, the state records the highest rice yield of nearly 3000 kg per hectare in India.

An attempt has been made in this paper to understand the effect of distribution of different climatic elements at different stages of the growth, to isolate and quantify technological components of the yield and combine these suitably into a pre-harvest prediction model. In view of its predominant importance in the rice cultivation, Punjab was selected for this analysis.

The approach in the present study is that of correlation and regression.

2. Past studies

As early as 1924, Fisher, studied influence of rainfall on the wheat yield. Runge (1968), Huda *et al.* (1975), Decker *et al.* (1976), Hough (1981) etc. have contributed significantly to crop weather studies. In India Rao *et al.* (1978) and Chowdhury and Sarker (1981) have attempted to estimate rice yields for different regions. The problem of the weather-technology interaction has also been studied by a number of workers. Newman *et al.* (1976) substituted a single trend yield variable to account for technology. Thompson (1969, 1970) examined effect of weather and technology on crop production. Leeper *et al.* (1974), Nelson and Dale (1978a, 1978b) also attempted to insulate the technilogy from the effect due to weather and obtained the estimates.

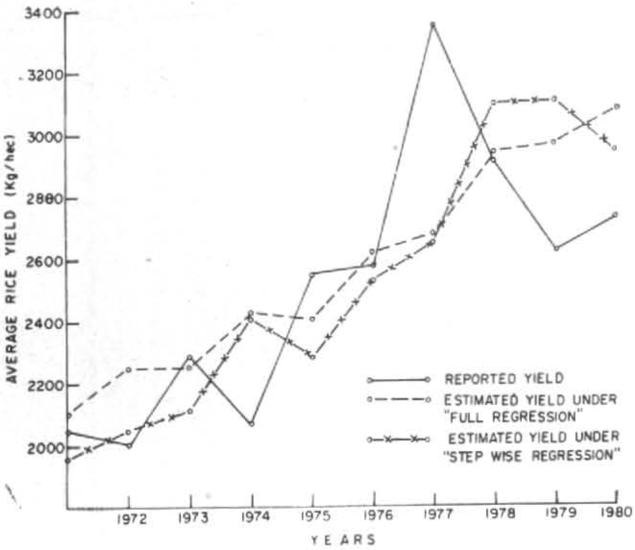

Fig. 1. Estimated technological yield

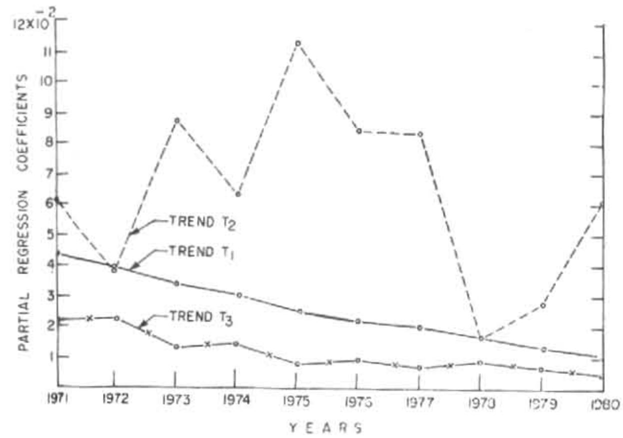

Fig. 2. Partial regression coefficients of the technological trend in the full regression

TABLE 1

Regression coefficients in stepwise regression equations fitted with data from 1941 through indicated year

Trend and weather variables	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
June rainfall	—	—	—	—	—	—	—	0.091	0.101	0.135
July rainfall	0.252	0.225	0.207	0.177	0.180	0.167	0.150	0.141	0.146	0.181
August rainfall	—	—	—	—	0.096	0.097	0.090	—	—	—
September rainfall	—	—	—	—	—	—	—	—	−0.134	—
September maximum temperature	—	—	—	—	—	—	—	—	−0.189	−0.110
September minimum temperature	—	—	—	—	—	—	—	—	—	—
Trend T_1	—	—	—	0.032	—	0.020	0.018	0.019	0.018	—
Trend T_2	0.279	0.261	0.242	—	0.218	0.083	0.078	—	—	0.080
Trend T_3	—	—	—	0.018	—	0.008	0.007	0.011	0.009	0.004

TABLE 2

Multiple correlation coefficients squared (R^2) for stepwise regression models for the periods

Period	Value	Period	Value
1941-70	0.85	1941-75	0.96
1941-71	0.89	1941-76	0.97
1941-72	0.90	1941-77	0.96
1941-73	0.93	1941-78	0.97
1941-74	0.93	1941-79	0.97

3. Choice of the weather parameters

In the present study, rainfall for each of the months, June to September, has been considered. For a better appreciation of crop-growth-weather models no doubt, rainfall for smaller periods like weeks should be incorporated, but in the present case, consideration of shorter duration rainfall would have considerably increased the number of independent variables and hence this had to be abandoned. Temperature is the other important parameter in the models. Since active growth and reproductive phase normally take place in September, the maximum and the minimum temperatures for this month alone were taken as independent parameters. The multiple regression model thus includes the following weather variables :

(1) June rainfall, (2) July rainfall, (3) August rainfall, (4) September rainfall, (5) September maximum temperature and (6) September minimum temperature

4. Data and method of analysis

4.1. *Crop data*

The rice production and acereage data were collected for all the districts in the state from 1941 to 1980 from Economic and Statistical Adviser, New Delhi. From these figures mean yearly yield for the state as a whole, was computed.

4.2. *Weather data*

The monthly rainfall data were collected from a well distributed network consisting of Ludhiana Patiala, Amritsar, Ferozpur, Jullunder, Sangrur, Kapurthala, Bhatinda and Gurudaspur observatories for the years 1941 to 1980 and the arithmetic mean for each months of June to September, obtained. The maximum and minimum temperature data of September has been collected in respect of the Amritsar, Bhatinda, Ferozpur, Kapurthala, Ludhiana and Patiala observatories and its mean was similarly computed.

4.3. *Normality approach*

Rao *et al.* (1971) found that rainfall over India does not follow a normal distribution but could be converted into a Gaussian distribution through suitable transformation. If μ and σ^2 are respectively the mean and variance of any set X_i, then $Z=(x-\mu)/\sigma$ is normally distributed with mean as zero and the standard deviation equal to unity. In the present analysis the rainfall and temperatrue parameters have been converted into a normal series using this technique.

4.4. *Agro-technology*

On plotting the average rice yield of Punjab from 1941 to 1979 it is seen that there is a marked and consistent increase from 1960-61 onwards. The area under irrigation and the consumption of fertiliser inputs are also reported to have increased from this year (Frankel 1971). The year 1960 is thus taken as the limiting year for studying the agro-technological impact on the yield.

The model uses three technological variables, *viz.*,

(*i*) A linear time variable which increases by one from 1941 to 1960 and thereafter remains constant (designated T_1).

(*ii*) Assuming absence of time trend upto 1960 and thereafter increasing the trend each year by one from 1961 onwards (designated T_2).

(*iii*) $T_3 = (T_2)^2$

With the introduction of technological trends, the model can be expressed as general linear regression

$$Y = \alpha_0 + \Sigma \alpha_i Z_i + \Sigma \beta_j T_j + \epsilon$$

where Y is the dependent parameter (*i.e.*, yield), α_0, α_i and β_j are the regression coefficients, Z_i the independent parameter (weather), T_j the independent parameter (technological trend) and ϵ is the random error.

TABLE 3

Departures (%) between reported yield and those estimated from "full regression" and estimated from stepwise regression

Data set used	Reported yield (kg/ha) in succeeding year	Estimated yield (kg/ha) with actual weather and trend	Percentage departure between columns (3) & (2	Estimated yield (kg/ha) with normal weather and trend	Percentage departure between columns (5) &(2)	Estimated yield (kg/ha) with actual weather and trend for the previous year	Percentage departure between columns (7) & (2)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			(a) Estimated from "full regression"				
1941-70	2042	1993	—2	2106	+3	1879	—8
1941-71	2006	2176	+8	2255	+12	1963	—2
1941-72	2289	2164	—5	2256	—1	2055	—10
1941-73	2072	2299	+11	2425	+17	2063	0
1941-74	2553	2402	—6	2410	—6	2297	—10
1941-75	2583	2661	+3	2623	+1	2535	—2
1941-76	3362	2523	—25	2681	—20	2401	—29
1941-77	2918	3078	+5	2950	+1	2919	0
1941-78	2632	2986	+13	2981	+13	2837	+8
1941-79	2741	3377	+23	3093	+13	3240	+18
			(b) Estimated from stepwise regression				
1941-70	2042	1942	—5	1963	—4	1881	—8
1941-71	2006	2033	+1	2050	+2	1969	—2
1941-72	2289	2099	—8	2105	+8	2036	—11
1941-73	2072	2358	+14	2425	+17	2215	+7
1941-74	2553	2359	—8	2282	—11	2293	—10
1941-75	2583	2600	+1	2536	—2	2484	—4
1941-76	3362	2612	—22	2652	—21	2493	—26
1941-77	2918	3195	+9	3107	+7	3013	+3
1941-78	2632	3173	+21	3118	+18	3000	+14
1941-79	2741	3311	+21	2962	+8	3188	+16

4.5. *Analytical procedure*

In this paper two different regression techniques have been used to build the regression model. All the independent variables (weather and trend) were regressed in the first approach (hereafter called the "full" regression) irrespective of whether a particular parameter was significant or not. This multiple variable linear model is analogous to that used by Bartholic *et al.* (1975) and Thompson (1975).

The second approach utilises the stepwise regression procedure as outlined by Draper and Smith (1966). A critical value of 2.0 was assigned for addition or deletion of any variable. This procedure reduces the large number of independent variables of the "full" regression approach. The "full" and the stepwise regression models were computed for weather, trend and the rice yield data for each of the 10 periods, *viz.*, 1941-70, 1941-71 etc to 1941-79.

For any year the yield was predicted based on parameters for the period ending the previous year. For example based on regression for the period 1941-70, the yield for the year 1971 was predicted. Using specific period of data, the "full" approach was adopted to predict the technological yield, *i.e.*, the yield with normal weather for the following year. Here, normal weather is defined as that weather when the departure from the average for that particular set of data used is zero. Thus, the technological yield for the "full" approach was estimated by inserting zeros for the departures from the normal weather variables.

As may be expected, the technological component of the yield after certain number of years must attain a particular level and stablise itself. This aspect of the yield has been examined by inserting actual weather conditions for an year in the model but using the trend value for the preceding year.

5. Results and discussion

The variables obtained in the stepwise model are given in Table 1 alongwith the technological variables, T_1, T_2 and T_3. The July rainfall was found to be a significant predictor in all the data sets. The coefficient for July rainfall ranged from 1.4 kg/cm for 1941-77 period to 2.5 kg/cm for 1941-70 period. The rainfall during August is significant for the periods 1941-74 to 1941-76 while that for June for periods 1941-77 to 1941-79, whereas the September rainfall was found significant only for the period 1941-78 where it was negatively correlated. The maximum temperature during September was found significant only for the periods 1941-78 and 1941-79 and it exerted depressing effect on the yield. Minimum temperature did not have any influence on the rice yield.

For each of the stepwise regression included in Table 1, the coefficient of determination 'R^2' is given in Table 2. The 'R^2' values are quite high and become more or less constant for the period 1941-75 onwards.

The technological component of the yield under 'normal' weather with 'full' and stepwise regression are shown in Fig. 1. The predicted technological yield for 'full' regression maintains an increasing trend, in agreement with the increase in the agricultural technology. The low actual yield in 1979, together with unfavourable weather significantly decreased the technological prediction for 1980. The preceding year included in the regression analysis is seen to exert much influence, in determining the regression equation and the following year's yield estimates and this is the limitation of the above methods.

The technological trend coefficients obtained in the analysis for the "full" regression is shown in Fig. 2. The coefficient for trend T_2, the second linear term is highly unstable and oscillates widely from year to year. Such instability suggest that the equation based on such trend is not the ideal predictive model. In contrast, the coefficient for T_1 and T_3 show in general a decreasing trend and perhaps may become more stable with increase in years to allow more accurate estimate of the effect of technology. By and large, the coefficients account for large variability in the technological prediction of yield.

6. Verification of the models

Both the 'full' regression and the stepwise regression models developed for specified data sets were tested with the actual data for the next year. This was done for :

(a) normal weather and actual trend,

(b) actual weather and actual trend and

(c) actual weather and the trend for the previous year.

The results of the analysis are shown in Table 3. The table shows the combined effect of the technology and the actual weather on the predicted yield for both the approaches. Both the predicted yields are significantly lower in 1977 and too large in 1980. These errors result mainly from the sensitive nature of the model to the last year's yield included in the regression. It may be seen that except for a slight decrease in 1977, the yield constantly increases for full regression. The stepwise regression also reveal, in general, increasing trend but to a lower degree.

7. Concluding remarks

A set of three statistical regression models have been developed in the above study for rice yield estimation for Punjab adopting the "full regression" method and the stepwise regression approach and compared. These are also tested for their reliability in yield prediction. Effect on the crop yield caused by changes in the weather and the technology has been compared by the three methods. The three time trend technology variables used in the analysis generally revealed yearly variability in predicting technological yield, *i.e.*, the yield under normal weather conditions. The results obtained are useful as they exhibit the effect of choosing the three technological trend parameters and stepwise and full regression methods. Nevertheless it is felt there is need for determining independent technological variable in crop-weather studies.

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