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Models for studying rice crop-weather relationship

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सार — पुरी जिले की चावल की पैदावार पर फसल की बढ़वार के विभिन्न चरणों में मौसम परिवर्तियों के प्रभाव के अध्ययन के लिये तथा पैदावार का पूर्वानुमान बताने के लिये विभिन्न निदर्शों पर कार्य किया गया है।

परिणामों से पता चलता है कि औसत से अधिक अधिकतम दैनिक तापमान के प्रभाव फसल पकने की अवस्था में लाभकारी, तथा जननात्मक अवस्था में हानिकारक रहा जबकि आरंभिक विकास सक्रिय तथा पश्च-वानस्पतिक चरणों में प्रभाव अस्थिर रहा। न्यूनतम तापमान में वृद्धि का प्रभाव फसल की आरंभिक पश्चवानस्पतिक तथा जननात्मक अवस्था में लाभकारी, फसल पकने की अवस्था में हानिकारक तथा सक्रिय वानस्पतिक अवस्था में अस्थिर रहता है। आमतौर पर औसत से अधिक सापेक्ष आर्द्रता तथा वर्षा का फसल की समस्त बढ़वार के दौरान लाभकारी तथा पकने की अवस्था में हानिकारक प्रभाव पाया गया। वर्षा तथा वर्षा दिवसों की संख्या में वृद्धि के प्रभाव की पश्च-वानस्पतिक अवस्था में अस्थिर, जननात्मक अवस्था में लाभकारी तथा फसल पकने की अवस्था में हानिकारक रहे। दिन में चमकती धूप के घण्टों में वृद्धि के प्रभाव फसल की आरंभिक बढ़वार, सक्रिय वानस्पतिक तथा जननात्मक अवस्था में हानिकारक, पश्च-वानस्पतिक अवस्था में अस्थिर तथा फसल पकने की अवस्था में लाभकारी रहे।

पूर्वानुमान निदर्श पर किए गए अध्ययन से ज्ञात होता है कि अधिकतम तापमान व धूप की अवधि में बारहवीं सप्ताह (अगस्त के तृतीय सप्ताह) तक के आंकड़ों पर आधारित निदर्श चावल की उपज पूर्वानुमान के लिए उचित है क्योंकि इसके द्वारा उपज के विचरण का लगभग 91 प्रतिशत विचरण स्पष्ट हो जाता है। अतः पुरी जिले में चावल की उपज का पूर्वानुमान कटाई से ढाई माह पूर्व सम्भव है।

ABSTRACT. Various models to study the effects of weather variables on rice yield at different stages of crop growth and to forecast its yield for Puri district have been attempted.

The results indicated that above average maximum daily temperature had beneficial effects during ripening stage; detrimental effects during reproductive stage of the crop while in the initial growth, active and lag vegetative phase effects were fluctuating. The effect of increase in minimum temperature was beneficial during initial, lag vegetative and reproductive stages, detrimental during ripening stage and fluctuating during active vegetative stage. Above average relative humidity and rainfall had beneficial effects throughout the growth and detrimental effects during ripening phase of the crop in general. The effects of rainfall and increase in number of rainy days were fluctuating upto lag vegetative, beneficial during reproductive and detrimental during ripening stage of the crop. Effects of increase in sunshine hours were detrimental during initial growth, active vegetative and reproductive stages, fluctuating during lag vegetative and beneficial during ripening stage of the crop.

Study of forecast model revealed that the model using data on maximum temperature and sunshine hours upto 12th week (*i.e.*, third week of August) was appropriate for forecasting rice yield as it explained 91% variation in yield. This suggests that forecasting rice yield is possible for Puri district 2½ months before harvest.

1. Introduction

Individual effects of weather factors on crop yields have been studied by Fisher (1924), Huda *et al.* (1975), Jain *et al.* (1980). Yield forecast models based on weather factors have been constructed by Agrawal *et al.* (1980) and Jain *et al.* (1980). We have further modified these models in this paper to study individual effects of weather factors on rice yield and its forecast for Puri district (Orissa).

2. Materials and methods

This study has been made for Puri districts, Orissa which is situated at 20 deg. 15′ N latitude and 85 deg. 50′E longitude. It receives an annual rainfall of about 1445 mm, 90% of which is received during mid-June to mid-October. Paddy is the principal crop of the kharif season. It is mostly rainfed crop.

Weekly weather data on average daily maximum and minimum temperature, relative humidity at 7 hr and 14 hr, total rainfall, number of rainy days and sunshine hours from 1952 onward till 1979, were obtained from I.M.D., Pune. District yield figures were collected from D.E.S., New Delhi. In all, 19 years data were available for analysis after leaving missing values.

2.1. *Crop season*

It is sown in the month of June and harvested in November. The early five weeks of growing season

TABLE 1

Coefficient of determination (R^2) under different models

Weather variables	Model							
	I	II	III	IV	V	VI	VII	VIII
Maximum temperature	0.79 (3)	0.75 (3)	0.86 (3)	0.83 (3)	0.79 (3)	0.76 (3)	0.86 (3)	0.85 (3)
Minimum temperature	0.73 (2)	0.71 (2)	0.76 (2)	0.76 (2)	0.74 (2)	0.72 (2)	0.77 (2)	0.77 (2)
Relative humidity (7 hr)	0.76 (2)	0.76 (2)	0.80 (2)	0.80 (2)	0.71 (1)	0.71 (1)	0.80 (2)	0.80 (2)
Relative humidity (14 hr)	0.72 (2)	0.67 (2)	0.82 (2)	0.81 (2)	0.73 (2)	0.67 (2)	0.82 (2)	0.81 (2)
Rainfall	0.63 (1)	0.63 (1)	0.80 (2)	0.80 (2)	0.63 (1)	0.63 (1)	0.80 (2)	0.80 (2)
No. of rainy days	0.69 (1)	0.69 (1)	0.86 (2)	0.86 (2)	0.69 (1)	0.69 (1)	0.86 (2)	0.86 (2)
Sunshine hours	0.73 (2)	0.79 (3)	0.88 (2)	0.87 (2)	0.80 (3)	0.80 (3)	0.89 (2)	0.89 (2)

Figures in parenthesis denote number of significant variables included in the model

covering 11 June to 15 July correspond to early growth phase. This includes period from sowing to emergence and initial growth of the crop. Grand growth phase from 9 July to 7 October includes active, lag vegetative and reproductive growth periods. Critical stages of this phase are tillering, ear initiation and flowering. Maturity phase includes the ripening stage of the crop covering the period from 8 October to 11 November.

2.2. *Statistical analysis*

The weekly weather data covering full crop season from 28 May (about a fortnight before sowing) to harvest were utilised for studying the effects of weather variables on yield while data of partial crop season were utilised for developing forecast models. Data starting a fortnight before sowing were considered as this period is expected to have effect on establishment of the crop.

2.2.1. *Models studied*

We have modified the model (Jain *et al.* 1980) by expressing effects of changes in weather variables on yield in w-th week as a linear function of respective correlation coefficients between yield and weather variables. As trend effect on yield was significant, its effect was removed from yield while calculating correlation coefficients of yield with weather variables to be used as weights. Effects of second degree terms of weather variables were also studied.

In all we have studied eight models obtained from earlier model and its modifications as suggested above. The eight models were as given below :

Model I : This is the earlier model (Jain *et al.* 1980).

$$Y = a + b_0 \sum_{w=1}^{n} X_w + b_1 \sum_{w=1}^{n} r_{xy(w)} X_w + b_2 \sum_{w=1}^{n} r^2_{xy(w)} X_w + cT$$

$$= a + b_0 Z_0 + b_1 Z_1 + b_2 Z_2 + cT$$

where Y is rice yield (kg/ha); a, b_j (j=0, 1, 2) and c are constants; n is number of weeks upto the time of harvest; w is week identification; X_w is the value of weather variable under study in w-th week; $r_{xy(w)}$ is correlation coefficient between yield and weather variable in w-th week.

Model II : In this model effects of weather on yield in different weeks were expressed as linear function of respective correlation coefficients of weather variables and yield.

The model becomes as

$$Y = a + b_0 Z_0 + b_1 Z_1 + cT$$

Model III & IV : The models are same as models I and II respectively except that $r_{xy(w)}$ is obtained using yield adjusted for trend effect.

Model V : This is obtained by including quadratic terms of weather variables in model I, as such the model becomes :

$$Y = a + b_0 \sum_{w=1}^{n} X_w + b_1 \sum_{w=1}^{n} r_{xy(w)} X_w + b_2 \sum_{w=1}^{n} r^2_{xy(w)} X_w + b_{00} \sum_{w=1}^{n} X_w^2 + b_{11} \sum_{w=1}^{n} r_{x^2y(w)} X_w^2 + b_{22} \sum_{w=1}^{n} r^2_{x^2y(w)} X_w^2 + cT$$

$$= a + b_0 Z_0 + b_1 Z_1 + b_2 Z_2 + b_{00} Z_{00} + b_{11} Z_{11} + b_{22} Z_{22} + cT$$

Model VI—This is obtained by including quadratic terms of weather variables in model II, as such the model becomes :

$$Y = a + b_0 Z_0 + b_1 Z_1 + b_{00} Z_{00} + b_{11} Z_{11} + cT$$

Model VII & VIII : Same as models V and VI respectively except that correlation coefficients are obtained using adjusted yield.

Data on relative humidity have been transformed into arc-sine root proportion as they were in percentages. Square root transformation $\sqrt{x+\frac{1}{2}}$ was used for data on number of rainy days. Stepwise regression was used to select significant generated variables.

The effects on yield per unit change in weather variables in w-th week have been calculated by differentiating the equations with respect to X_w.

2.2.2. *Forecast models*

Forecast models have been developed considering various combinations of weather variables. In order to study the performance of forecast model, yield forecast of subsequent year not included for obtaining forecast model was worked out.

3. Results and discussion

We have studied eight models to obtain suitable model for studying crop-weather relationship. The coefficient of determination (R^2) for the eight models studied are presented in Table 1. Perusal of the table indicated that (*i*) models using correlations based on yield adjusted for trend effect were better than the ones using simple correlations, (*ii*) inclusion of quadratic term of weather variables and also second power of correlation coefficient did not improve the model. This indicates that model IV can be used to study effects of weather on rice yield and its forecast.

3.1. *Effect of climatic variables on rice yield*

The effects of one unit increase above average in climatic parameters at different growth stages of the crop have been discussed in this section. The effects are given in Table 2. Effects of one unit decrease below the average can be obtained by reversing the vertical scale.

3.1.1. *Effect of temperature*

The multiple regression equation obtained for maximum temperature was :

$$Y = 1306.23 + 10.62\, Z_0 + 70.35\, Z_1 + 24.85 T \quad (R^2 = 0.85^{**})$$

During pre-sowing, initial growth phase, active and lag vegetative stages the effect of 1°C above the average was fluctuating. Pronounced beneficial effect was observed during 10th week. The effects were detrimental during reproductive stage of the crop. During ripening stage, beneficial effects of rise in temperature above average were observed in general.

The multiple regression equation obtained for minimum temperature was :

$$Y = -2174.16 + 28.66\, Z_1 + 17.66\, T \quad (R^2 = 0.76^{**})$$

During pre-sowing and initial growth phase, the beneficial effects were observed in general. During active vegetative stage, the effect was fluctuating. During lag vegetative and reproductive stages, beneficial effects were observed by rise in temperature above average. The effects were detrimental during ripening stage of the crop.

3.1.2. *Effect of relative humidity*

The multiple regression equation obtained for relative humidity (7 hr) was :

$$Y = -2192.73 + 15.71\, Z_1 + 18.64\, T \quad (R^2 = 0.80^{**})$$

The effects were in general beneficial throughout the growth of the crop. The effects were pronounced in 13th and 15th week. Small adverse effects were observed during pre-sowing and 7th, 10th and 14th weeks. During ripening stages the effects were detrimental.

The multiple regression equation obtained for relative humidity (14 hrs) was :

$$Y = -2854.28 + 14.95\, Z_1 + 23.64\, T \quad (R^2 = 0.80^{**})$$

Small beneficial effects of rise in humidity above average were observed throughout the crop growth except in 10th week. During ripening phase the small adverse effects were observed in general.

3.1.3. *Effects of rainfall and number of rainy days*

The multiple regression equation obtained for rainfall was :

$$Y = -651.38 + 15.01\, Z_1 + 20.11\, T \quad (R^2 = 0.80^{**})$$

The effect of 1 cm increase in total weekly rainfall was beneficial in general throughout the crop growth. The small detrimental effects were observed duing pre-sowing and 3rd, 6th and 11th weeks. During ripening stage small adverse effects were observed except in the last week.

The multiple regression equation obtained for number of rainy days was :

$$Y = -840.97 + 224.14\, Z_1 + 20.06\, T \quad (R^2 = 0.86^{**})$$

The effects of increase in number of rainy days were fluctuating upto lag vegetative stage. During reproductive stage the effects were beneficial while detrimental effects were observed in ripening stage except the last two weeks.

3.1.4. *Effect of sunshine hours*

The multiple regression equation obtained was :

$$Y = -623.92 + 35.05\, Z_1 + 23.82\, T \quad (R^2 = 0.88^{**})$$

The effect of 1 hr increase in sunshine hour was detrimental during initial growth, active vegetative and reproductive stages of the crop in general. During lag vegetative stage, the effects were fluctuating. Beneficial effects were observed during pre-sowing and ripening stage of the crop.

3.2. *Forecast model and time of forecast*

To find suitable time of forecast, model IV was fitted using partial crop season data taking various important weather variables singly and in combinations. The model used was :

$$Y = a + \sum_{i=1}^{p} \sum_{j=0}^{1} b_{ij} Z_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=0}^{1} b_{ii'j} Z_{ii'j} + cT$$

$$Z_j = \sum_{w=1}^{m} r_{iw}^{j} X_{iw}$$

$$Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{iw} X_{i'w}$$

p = number of weather variables used, m is week of forecast, $r_{iw}/r_{ii'w}$ are the correlation coefficients of yield and the i-th weather variable (X_i)/the product of

**denotes significance at 1% level.

TABLE 2

Per cent change in yield per unit increase in weather variable over its average value

Week No.	Temp.		R.H.		Rainfall	Rainy days	Sun-shine hours
	Max.	Min.	7 hr	14 hr			
1	—1.63	0.67	—0.31	0.14	—0.45	—2.04	1.16
2	1.74	1.22	—0.39	—0.08	—0.24	—8.04	0.33
3	0.13	1.74	—0.08	0.12	—0.32	—0.62	—1.82
4	0.63	1.32	0.02	0.02	0.05	—1.82	—1.63
5	0.99	—0.09	0.62	0.50	0.34	6.25	—0.44
6	—0.20	1.05	0.12	0.21	—0.31	—4.11	0.50
7	—1.00	—0.43	—0.47	0.12	0.21	9.44	0.66
8	0.38	—0.76	0.27	0.15	0.75	—2.57	0.32
9	—1.65	0.19	0.19	0.54	0.73	6.15	—2.21
10	3.80	0.003	—0.42	—0.42	0.08	—4.68	—0.90
11	—1.24	0.71	0.53	0.07	—0.54	—0.05	—0.68
12	—0.20	—1.09	0.36	0.13	0.65	3.04	—0.09
13	—1.95	—0.29	0.88	0.48	0.53	3.14	—1.20
14	1.53	0.68	—0.23	0.15	—0.002	—5.83	0.79
15	—1.63	0.49	1.00	0.58	0.38	5.45	—1.55
16	0.41	1.23	0.17	0.29	0.16	—6.18	0.92
17	—0.44	1.40	0.49	0.63	0.43	7.15	—0.65
18	—1.41	1.26	0.56	0.16	0.09	4.38	0.41
19	—1.55	1.01	0.57	0.61	0.23	6.59	0.19
20	—1.57	0.41	0.17	0.49	0.07	7.87	—1.02
21	—0.19	—1.47	0.20	—0.04	—0.03	—1.87	0.71
22	—0.29	—0.33	—0.29	0.09	—0.13	—2.07	0.25
23	1.07	—0.04	—0.08	—0.38	—0.17	—4.28	0.74
24	0.28	—0.47	—0.53	—0.30	0.002	1.67	—0.03
25	—1.04	—0.30	0.21	—0.34	0.40	7.25	1.47

Note : Unit of the weather variable has been given in the text.

the two weather variables (X_i and X_i') in w-th week. (Here i=1, 2, . . ., 7 corresponds to maximum temperature, minimum temperature, relative humidity at 7 hr and 14 hr, rainfall, number of rainy days and sunshine hours respectively). The model has been fitted for different values of m (m=12, 13, ..., 18). The data after 18th week have not been used as the idea was to forecast yield well in advance of harvest.

The coefficient of determination (R^2) at different points of time are given in Table 3. Perusal of table reveals that 12th week (3rd week of August) is the appropriate time for forecasting rice yield in Puri district as there is not much improvement in the value of R^2 by including data of later periods.

The performance of model based on maximum temperature and sunshine hour only was at par with the one using all variables simultaneously. Therefore, model using maximum temperature and sunshine hour is recommended for operational convenience. Thus the model to be used is :

$$Y = 412.73 + 9.21\ Z_{10} + 82.28\ Z_{11} + 35.74\ Z_{71} + + 20.52\ T$$

3.3. *Yield forecast*

Yield forecast of 1979 was obtained from the above suggested model based on data upto 1978. The forecast worked out to 930 kg/ha as against 1056 kg/ha. The per cent deviation from actual yield is 11%.

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TABLE 3

R^2 for forecast models at different points of time

Variables used	Week of forecast						
	12	13	14	15	16	17	18
Maximum temp.	0.79 (3)	0.82 (3)	0.84 (3)	0.88 (3)	0.86 (3)	0.86 (3)	0.84 (3)
Sunshine hours	0.81 (2)	0.81 (2)	0.82 (2)	0.84 (2)	0.84 (2)	0.84 (2)	0.84 (2)
No. of rainy days	0.72 (2)	0.72 (2)	0.74 (2)	0.78 (2)	0.79 (2)	0.80 (2)	0.81 (2)
Max. temp. and sunshine hours	0.91 (4)	0.90 (4)	0.92 (4)	0.94 (4)	0.94 (4)	0.93 (4)	0.92 (4)
All variables	0.93 (4)	0.86 (3)	0.91 (4)	0.92 (4)	0.92 (4)	0.95 (4)	0.94 (4)

Note : Figures within parenthesis denote number of significant variables in the model.

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