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Effect of climatic variables on rice yield and its forecast

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ABSTRACT. An attempt has been made in this paper to study the effect of climatic variables on rice yield at different stages of crop growth as also to forecast rice yield using climatic variables.

The results show that the crop reacts differently to climatic parameters during different stages of its growth. Above average maximum daily temperature is beneficial during active vegetative and ripening stages and detrimental during lag vegetative stage of the crop. A rise in relative humidity (at 7 hr) above average is beneficial during tillering and early part of reproductive stage but produces adverse effects during ripening stage. Above average relative humidity (at 14 hr) is beneficial during both early part of lag vegetative stage and later part of reproductive stage. The effect of increase in total weekly rainfall is in general beneficial throughout the crop season. Above average daily sunshine hour is beneficial during active vegetative and ripening stages but produces adverse effects in the lag vegetative and reproductive stages.

The study on yield forecast shows that a reliable forecast is possible after about 2 months of sowing assuming weather to be normal after that. This as such calls for issuing revised forecasts periodically in case weather departs from normal.

1. Introduction

Climatic variables affect the crop differently during different stages of development. These effects are manifested through plant characteristics like height, number of tillers, leaf area and number of earheads which ultimately affect the yield. Further, climate may also create conditions which may be favourable or unfavourable for growth of diseases and pests, thereby affecting the crop yield. The effect of climatic parameters at different growth stages of the crop may help in understanding their response in terms of the final yield and also provide a forecast of crop yield in advance of harvest. An attempt has been made in this paper to understand the effects of climatic variables on rice yield at different stages of crop growth as also to forecast rice yield using climatic variables.

2. Materials and methods

This study pertains to Raipur district in Madhya Pradesh, which is situated between 19 deg. 51′ & 21 deg. 52′N latitude and between 81 deg. 13′ & 83 deg. 16′E longitude. It falls in the category of moderate rainfall area with an average annual rainfall of 128.37 cm of which 87 per cent is received during 1 June to 30 September. This period covers a major part of the kharif crop season. The soils are clay to light sandy clay. Total area under foodgrains in the region is 11,02,000 hectares of which only 20 per cent is irrigated. Paddy is the principal kharif crop of the region occupying 60 per cent of the total cropped area. It is sown in the month of June and harvested in October-November.

District figures of rice yield for 17 years available for the period from 1947 to 1971 were obtained from the Directorate of Economics and Statistics, New Dehi. Weekly data on weather variables namely average daily maximum temperature, relative humidity at 7 and 14 hr, sunshine hours and total weekly rainfall were taken from India Meteorological Department, Pune for Labhandi farm which is 4 km away from

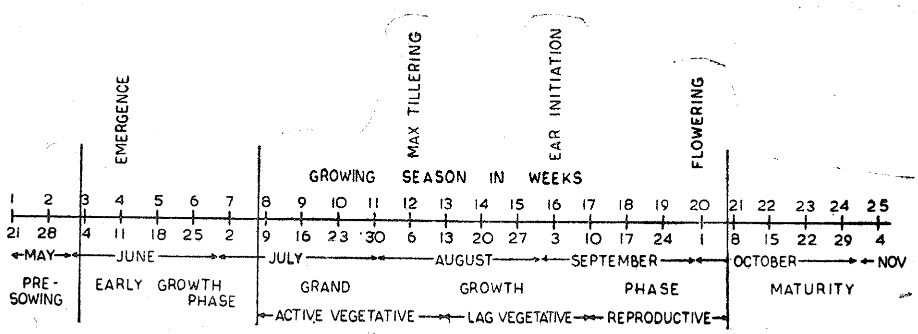

Fig. 1. Crop season of rice

Raipur. The weekly data from 21 May (about a fortnight before sowing) to 11 November were utilised for the study. Data starting a fortnight before sowing have been considered as this period is expected to have a profound effect in the establishment phase of the crop.

2.1. *Crop season*

Various important stages of crop season from 4 June to 11 November are shown in Fig. 1.

2.1.1. *Early growth phase*

This phase comprises of early five weeks of growing season covering 4 June to 8 July. This includes the period from sowing to emergence and early growth of the crop. This period is characterised by decreasing maximum temperatures (40.2 to 31.3 deg. C); and sunshine hours (6.2 to 3.1 hr); rising relative humidity (58 to 88 per cent at 7 hr and 32 to 69 per cent at 14 hr) and increasing rainfall (25.5 to 100.5 mm).

2.1.2. *Grand growth phase*

This phase extending from 8 July to 7 October covers active vegetative, lag vegetative and reproductive growth periods. Critical stages of this phase are tillering, ear initiation and flowering. During this period maximum temperature and relative humidity (at 7 hr) remain more or less constant, maximum temperature varying from 29.9 to 31.0 deg. C and relative humidity (at 7 hr) from 88 to 90 per cent. Rainfall and relative humidity (at 14 hr) are high upto vegetative growth of the crop and then decrease during reproductive phase of the crop. Rainfall decreases from 64.5 to 24.2 mm and relative humidity from 74 to 61 per cent. Sunshine hours vary within a small range from 2.8 to 3.5 hr during active vegetative growth and then increase from 3.4 to 7.5 hr in the reproductive phase.

2.1.3. *Maturity phase*

This phase includes the ripening stage of the crop covering the period from 8 October to 11 November. This period is characterised by decreasing maximum temperature (31.3 to 29.3 deg. C), relative humidity (88 to 85 per cent at 7 hr and 58 to 37 per cent at 14 hr) and rainfall (15.1 to 1.0 mm); increasing sunshine hours (7.8 to 8.5).

2.2 *Statistical analysis*

2.2.1. *Effects of weather variables on yield*

The following model has been used to study the effects of weather variables on yield.

$$Y = A_0 + \sum_{j=0}^{2} a_j Z_j + cT$$

where Y is rice yield (kg/ha); A_0, a_j (j=0, 1, 2) and c are constants: T is year number included to correct for the long term upward or downward trend in yield, Z are generated weather variables defined as :

$$Z_j = \sum_{w=1}^{n} r^i_w X_w \Big/ \sum_{w=1}^{n} r^j_w$$

n is the number of weeks upto the time of harvest; w is week identification (it is 1 for the period from 21-27 May and 25 for the period from 4-11 November); X_w is the value of weather variables under study in the w^{th} week, $r^j{}_w$ is the correlation coefficient of yield with weather variable in the w^{th} week.

This is a modified form of model used by Hendricks and Scholl (1943), Stacy *et al.* (1957), Runge (1968) and Huda *et al.* (1975) where respective correlation coefficients are used as weights in place of week number in obtaining generated weather variables Z_j. The data on relative humidity were transformed into arc-sine root proportion as they were in percentages.

The effects on yield per unit change in weather variable in w^{th} week have been calculated by differentiating the equation with respect to X_w.

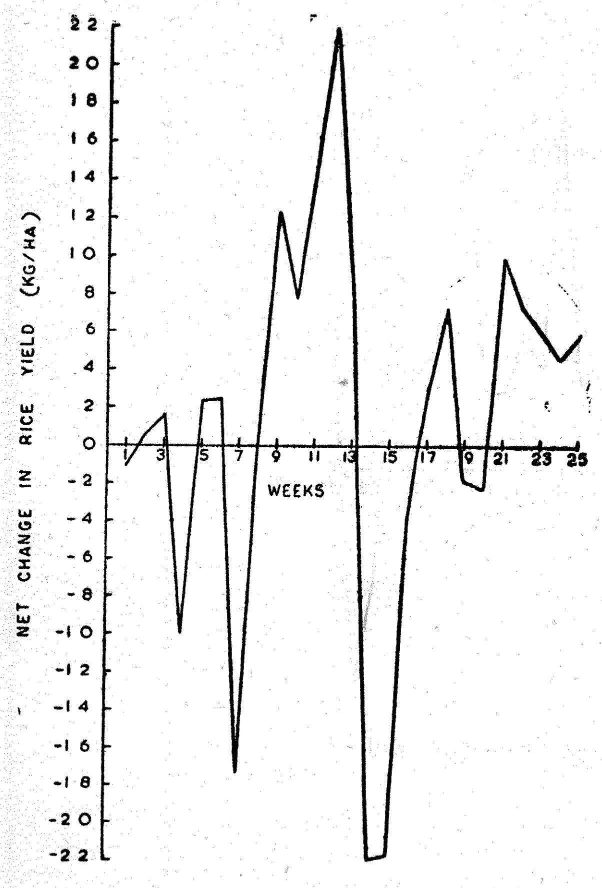

Fig. 2. Effect of 1°C above average maximum temp. on yield

2.2.2. *Yield forecast*

The extended form of the model described above taking all weather variables at a time has been used for forecasting yield in advance of harvest.

The model is :

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{2} a_{ij} Z_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=0}^{2} b_{ii'j} Q_{ii'j} + pcT$$

where, $Z_{ij} = \sum_{w=1}^{n} r^j_{iw} X_{iw} \Big/ \sum_{w=1}^{n} r^j_{iw}$ and

$$Q_{ii'j} = \sum_{w=1}^{n} r^j_{ii'w} X_{iw} X_{i'w} \Big/ \sum_{w=1}^{n} r^j_{ii'w}$$

X_{iw} is the value of the i^{th} weather variable in the w^{th} week; r_{iw} is the correlation coefficient of Y with the i^{th} weather variable in w^{th} week; $r_{ii'w}$ is the correlation coefficient of Y with the product of the i^{th} and the i'^{th} weather variables in w^{th} week; p is the number of weather variables $=5$; i, $i'=1, 2, \ldots, 5$ correspond respectively to maximum temperature, relative humidity at 7 and 14 hr, rainfall and sunshine hours.

Stepwise regression was used to select significant generated variables Z_{ij}'s and $Q_{ii'j}$'s. Further analysis was carried out including significant generated variables only.

In order to study the consistency of forecast, simulated forecasts of subsequent years (not included in the forecast equation) were worked out. Yields of subsequent years were forecasted with one month interval starting from 8th week after sowing. For forecasting, observed weather was used upto the time of forecast and normal values of weather variables for the remaining period upto harvest.

3. Results and discussion

Effect of climatic variables on rice yield

Effect of pre-sowing (first two weeks) weather on crop yield was negligible. Further discussion, therefore, covers the actual crop season of 23 weeks from 4 July to 11 November.

Effect of maximum temperature (*Fig.* 2)

The multiple regression equation obtained for average daily maximum temperature was $Y = -853.20 + 192.86\ Z_0 - 54.84 Z_1 - 101.97 Z_2 + 10.93\ T$. The coefficient of determination (R^2) was found to be 0.72 and it was significant at 1 per cent level of significance. During the initial growth phase, maximum temperature decreased from 39.5 to 30.9° C. During this period, the effect of 1° C above the average daily maximum temperature was not beneficial in general, indicating that the observed temperature was sufficient and further rise will have an adverse effect. However, very small beneficial effects were observed in the 1st, 3rd and 4th weeks after sowing.

During the active vegetative stage, the average daily maximum temperature decreased from 31.4 to 29.5°C. At this time the crop requires a higher temperature between 32°C and 34°C. Since the observed temperature was lower than the required during this time, a beneficial effect of rise in temperature was observed. This was as high as 22 kg/ha in 10th week after sowing which corresponds to maximum tillering stage. During lag vegetative stage, the maximum temperature remained more or less constant at 30°C. During this period, maximum temperature not exceeding 30°C is required. Adverse effects were observed in the last three weeks of this period. During reproductive stage, the maximum temperature fluctuated between 30.4 and 31.5°C. During this period, net change in yield fluctuated between +7.5 and —2.2 kg/ha.

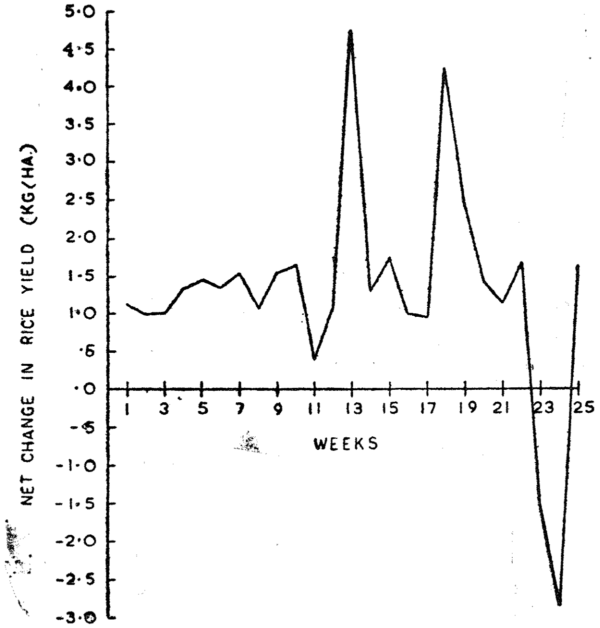

Fig. 3. Effect of 1°C above average transformed relative humidity (7 hr) on yield

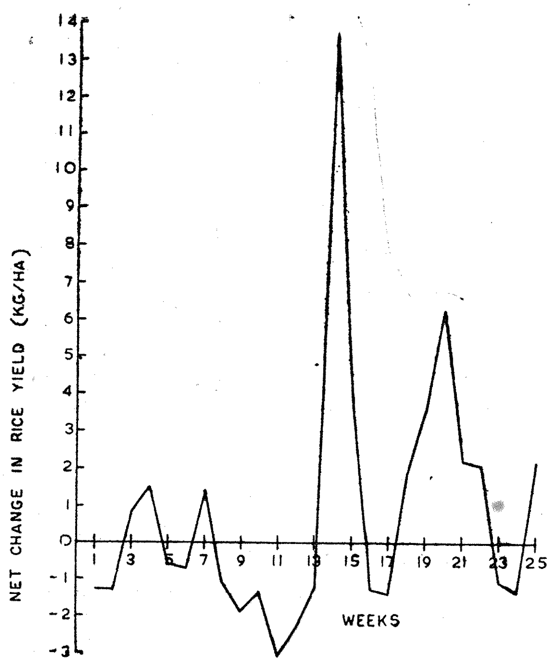

Fig. 4. Effect of 1° above average transformed relative humidity (14 hr) on yield

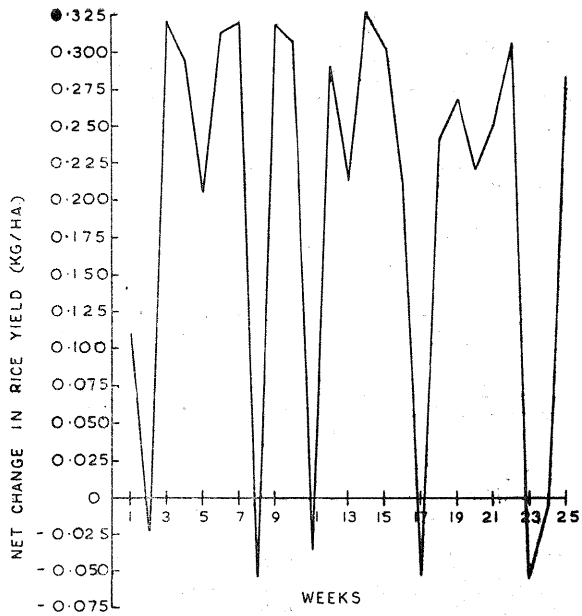

Fig. 5. Effect of 1 cm above average total weekly rainfall on yield

During ripening stage, the maximum temperature increased from 29.2 to 31.2°C. During this period, beneficial effect of rise in temperature was observed. This was expected as a higher temperature is required at the time of maturity.

Effect of relative humidity (*Figs*. 3 *and* 4)

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

$$Y = 2042.10 + 3.36\,Z_0 - 8.44\,Z_1 + 7.64\,Z_2 + 11.05\,T$$

The coefficient of determination (R_2) was 0.71 which was significant at 1 per cent level of significance.

The rise in humidity had a small beneficial effect in general throughout the crop season. However, large positive effect was observed in the 11th and 16th weeks after sowing which correspond respectively to the tillering and early reproductive stages of crop growth. The large negative effect was observed in the 21st and 22nd weeks after sowing which correspond to ripening stage. This is expected as during this period low humidity and high temperature are required.

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

$$Y = -912.66 - 33.29\,Z_0 - 11.55\,Z_1 + 64.22\,Z_2 + 11.63\,T$$

The coefficient of determination (R^2) was 0.82 and it was significant at 1 per cent level of signficance.

The effect of a rise in humidity at 14 hr was small upto 11th week after sowing but produced a large beneficial effect in the 12th and 13th weeks after sowing which correspond to the early part of lag vegetative stage. The rise in humidity had a beneficial effect during later part of the reproductive stage but during ripening stage, its effect was fluctuating.

Effect of rainfall (*Fig*. 5)

The multiple regression equation obtained for rainfall was $Y = -181.47 + 3.34\,Z_0 + 3.74\,Z_1 - 1.93\,Z_2 + 12.19T$. The coefficient of determination (R^2) was 0.70 and it was significant at 1 per cent level of significance. The effect of 1 cm increase in total weekly rainfall was in general beneficial throughout the crop season. This is expected as well distributed 1200 to 1300 mm rainfall is required for the rice crop whereas in Raipur the average total rainfall is about 800 mm. The negative effect during some week was almost negligible. These findings, thus, suggest that the crop production can be increased by supplying additional water through irrigation at appropriate stages of crop growth.

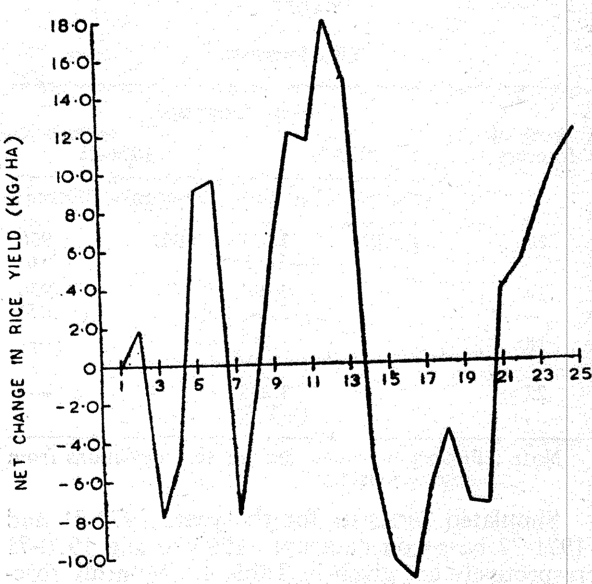

Fig. 6. Effect of 1 hr above average daily sunshine hours on yield

Effect of sunshine hours (*Fig*. 6)

The multiple regression equation obtained for sunshine hour was :

$$Y = 49.61 + 39.40Z_0 + 6.43Z_1 - 5.79Z_2 + 10.70T$$

The coefficient of determination (R^2) was 0.72 and it was significant at 1 per cent level of significance. The first two weeks period of early growth phase which corresponds to establishment of the crop, an increase in sunshine hours produced adverse effect but a beneficial effect was observed in the next two weeks. An increase in sunshine hours during active vegetative stage also had a beneficial effect on the crop. The increase in yield was as high as 18 kg/ha for 1 hour increase in average daily sunshine hours during 10th week after sowing which corresponds to the maximum tillering stage. During the growth phase starting from 12th week (after sowing) onwards adverse effect was observed due to increase in sunshine hours. This period corresponds to lag vegetative and reproductive stages of the crop. During ripening stage also, an increase in the sunshine hours was found to be beneficial.

Yield forecast

Forecast equation using significant generated variables was obtained as :

$$Y = -1297.60 - 1369.40\,Q_{231} + 2274.90\,Q_{232} - 22.75\,Q_{252} + 135.27\,Q_{351} + 7.41T$$

The coefficient of determination (R^2) was 0.91 and it was significant at 0.1 per cent level.

TABLE 1

Yield forecasts

Week of forecast	Year forecasted			
	1970-71		1971-72	
	Observed	Forecast	Observed	Forecast
10	1,209	1,011 (—16.5)	941	956 (+1.6)
14		1,061 (—11.4)		936 (—0.5)
18		1,113 (—7.9)		—
22		1,237 (+1.5)		—

NOTE : Figures in bracket are per cent deviations from observed yield.

Simulated forecasts for the years 1970-71 and 1971-72 based on data upto 1969-70 and 1970-71 respectively are given in Table 1. Monthly forecasts starting from 8th week onwards after sowing showed that the forecast improved with time in 1970-71 while in 1971-72 even in 8th week the forecast was quite close to the observed value. In 1970-71, the actual and normal weather were different after 8th week, causing improvement in forecast with time. In 1971-72, it was found that observed and normal values were quite close after 8th week, thus enabling us to get a reliable forecast, as early as 8th week after sowing.

The study shows that a reliable forecast is possible after about 2 months of sowing assuming that weather will remain normal thereafter. However, revised forecasts may be issued periodically in case weather shows significant departure from normal.

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