Mausam, (1983), 34, 2, 189-194

632.11 : 633.17

Joint effects of weather variables on rice yield

RANJANA AGRAWAL, R. C. JAIN and M. P. JHA

Indian Agricultural Statistics Research Institute, New Delhi

(*Received 21 December 1981*)

सार — फसल की बढ़वार के लिए विभिन्न चरणों में धान की पैदावार पर जलवायु के चरों के संयुक्त प्रभावों का अध्ययन करने का प्रयास किया गया है । सक्रिय कायिक चरण में आर्द्रता की वृद्धि से पैदावार पर औसत से अधिक अधिकत्तम तापमान के लाभकारी प्रभावों में वृद्धि होती है । दूसरी ओर इससे फसल की बढ़वार के अन्य चरणों में अपचायक प्रभाव कम हो जाते हैं । आर्द्रता में वृद्धि से सामान्यत: कुछ न कुछ लाभकारी प्रभाव होते हैं । तापमान में वृद्धि सहित अधिक वर्षा का फसल की बढ़वार पर लाभकारी प्रभाव पड़ता है ।

ABSTRACT. An attempt has been made to study the joint effects of climatic variables on rice yield at different stages of crop growth. Beneficial effects of above average maximum temperature on yield increased with rise in humidity during active vegetative phase while detrimental effects decreased in other phases of crop growth. The rise in humidity had small beneficial effects in general throughout the crop season. The effects increased with increase in temperature. Rise in temperature associated with high rainfall had beneficial effects during growth phase of the crop.

1. Introduction

Individual effects of weather factors on crop yields have been studied by Fisher (1924), Huda *et al.* (1975) and Jain *et al.* (1980). It is expected that the effects of weather factors are not independent as crop yield is influenced by the particular combinations of these factors in which they occur. For example, the effect of rainfall on yield depends not only upon the amount of rainfall and the time at which it occurs but also upon the levels of other weather factors that may be associated with it at that time. Hendricks and Scholl (1943), Stacy (1957) and Runge (1968) have studied joint effects of temperature and rainfall on crop yields. In the present study joint effects of some important combinations on rice yield have been studied.

2. Materials and methods

This study pertains to Raipur district in Madhya Pradesh. The details of location and agro-climatic conditions are given by Jain *et al.* (1980).

District figures of rice yield for 25 years available for the period from 1947 to 1973 are obtained from the Directorate of Economics and Statistics, New Delhi. Weekly data on weather variables, namely, average daily maximum temperature, relative humidity at 14 hr and total weekly rainfall are taken from the India Meteorological Department, Pune for Labhandi farm which is 4 km away from Raipur.

2.1. *Crop season*

Crop is sown in the month of June and harvested in October-November. Various important stages of crop season are shown in Fig. 1. For details, refer Jain *et al.* (1980).

2.2. *Statistical analysis*

To study joint effects of weather variables on rice yield the model used for studying effects of individual weather variables (Jain *et al.* 1980) has been extended by including interaction terms. The modified model is :

$$Y = A_0 + \sum_{j=0}^{2} a_{ij} Z_{ij} + \sum_{j=0}^{2} a_{i'j} Z'_{ij} + \sum_{j=0}^{2} a_{ii'j} Q_{ii'j} + c\,T \qquad (1)$$

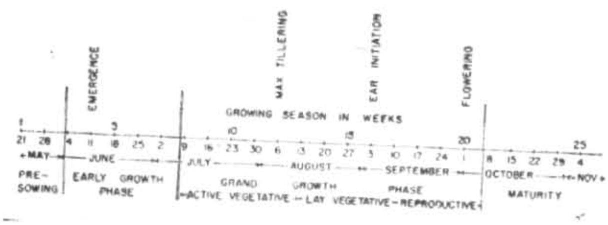


Fig. 1. Crop season of rice

where, Y is rice yield (k/ha): A_0, a_{ij}, $a_{i'j}$, $a_{ii'j}$ $(i, i' = 1, 2, 3; j = 0, 1, 2)$ and c are constants; T is year number included to correct for the long term upward or downward trend in yield, Z and Q are first and second order generated weather variables defined as :

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

and

$$Q_{ii'j} = \sum_{w=1}^{n} r^j_{ii'w} X_{iw} X_{i'w} \Big/ \sum_{w=1}^{n} r^j_{ii'w} \qquad (2)$$

n is number of weeks upto 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_{iw} is the value of i^{th} weather variables in w^{th} week (In this study $i=1, 2, 3$ corresponds to maximum temperature, relative humidity and rainfall respectively), 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.

Data on relative humidity have been transformed into arc-sine root proportion as they were in percentages.

Stepwise regression (Draper and Smith 1966) has been used to select the significant generated variables.

The rate of change of yield with respect to X_{iw} at any time w, can be obtained from equation (1) by taking the partial derivative of Y with respect to X_{iw}.

$$\frac{\partial Y}{\partial X_{iw}} = \sum_{j=0}^{2} \left[b_{ij} r^j_{iw} \Big/ \sum_{w=1}^{n} r^j_{iw} \right] +$$

$$\sum_{j=0}^{2} \left[b_{ii'j} r^j_{ii'w} X_{i'w} \Big/ \sum_{w=1}^{n} r^j_{ii'w} \right] \qquad (3)$$

The rate of change of yield with respect to X_{iw} at any time w thus appears as a function of correlation of yield and variable X_{iw}, correlation of yield and product of X_{iw} and $X_{i'w}$ and value of $X_{i'w}$. Using Eqn. (3), the rate of change of yield with respect to X_{iw} can be worked out for arbitrarily assigned values of $X_{i'w}$. Similarly, the rate of change of yield with respect to $X_{i'w}$, can be obtained by taking the partial derivative of Y with respect to $X_{i'w}$ given in Eqn. (1).

The assumption in this method are :

(*a*) That one unit change above or below average in weather variable effects rice yield by the same percentage but in opposite direction.

(*b*) The total effect on rice yield is directly proportional to the number of units of weather variables above or below average.

(*c*) The effect on rice yield in each week is independent of the effect in any other week.

3. Results and discussion

3.1. The joint effects of maximum temperature and relative humidity.

The multiple regression equation to study the joint effects of maximum temperature and relative humidity on yield :

$$Y = 929.01 : - 50.94 Z_{12} + 0.81 Q_{122} + 10.67 T$$

The coefficient of determination, 0.62, is significant at 1 per cent level.

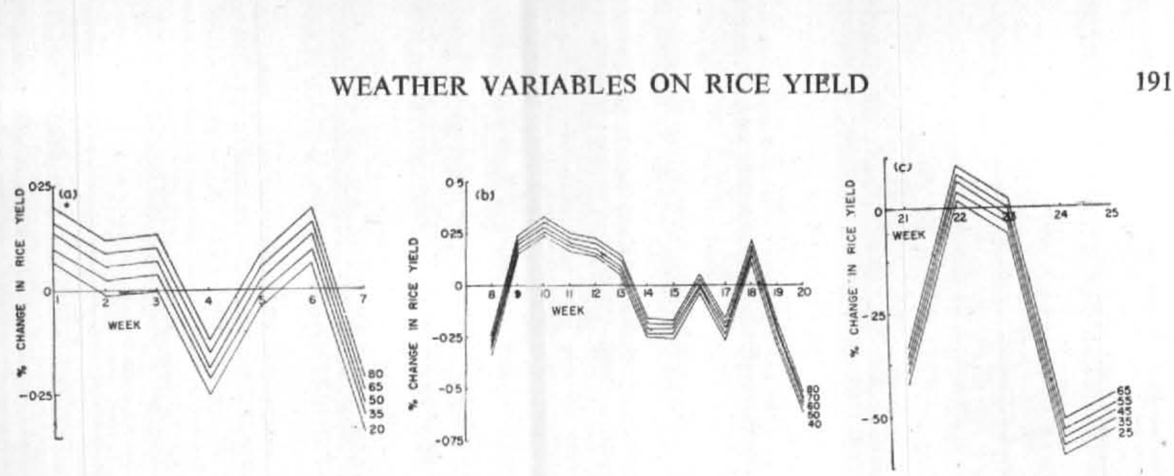
3.1.1. *Effect of maximum temperature at constant relative humidity*

The rate of change of final yield with respect to temperature at any week during the growing season for different values of relative humidity covering the observed range at the station has been computed from the equation:

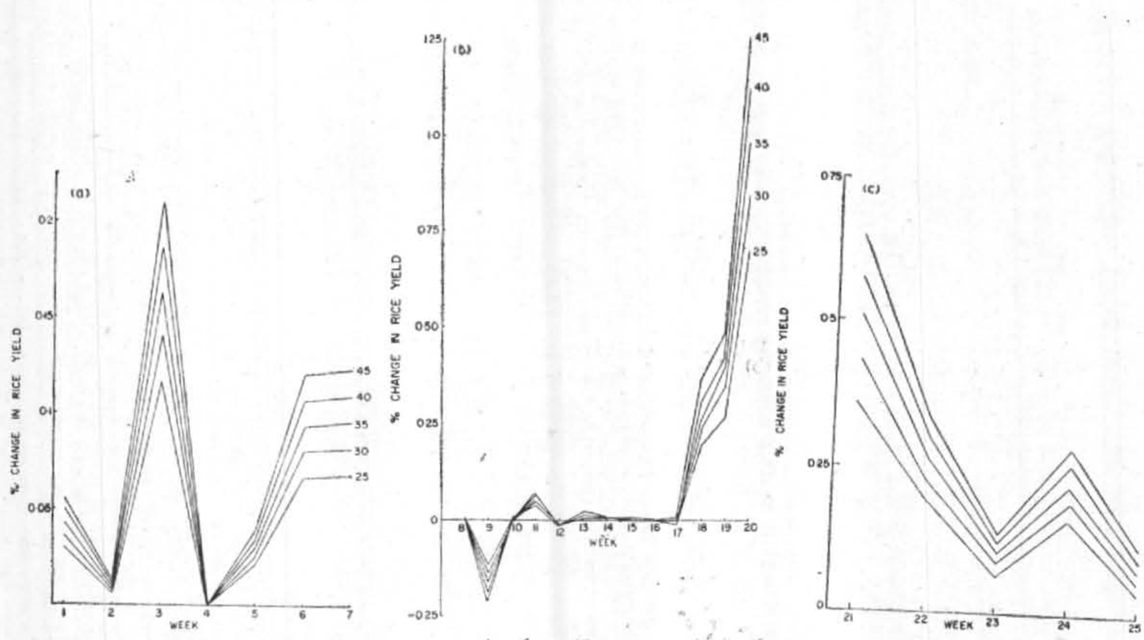
$$\frac{\partial Y}{\partial X_{iw}} = -50.94 \frac{r^2_{1w}}{\sum_{w=1}^{n} r^2_{1w}} + 0.81 \frac{r^2_{12w} X_{2w}}{\sum_{w=1}^{n} r^2_{12w}}$$

It is observed that beneficial effects of above average maximum temperature on yield increased with rise in humidity while detrimental effects decreased.

Per cent change in yield for each degree of temperature rise above average at different stages of crop growth is presented in Figs. 2 (a-c).



Figs. 2(a-c). Effect of 1°C above average maximum temperature on rice yield at different levels of relative humidity (14 hr) : (a) Initial growth phase, (b) Grand growth phase, (c) Ripening phase

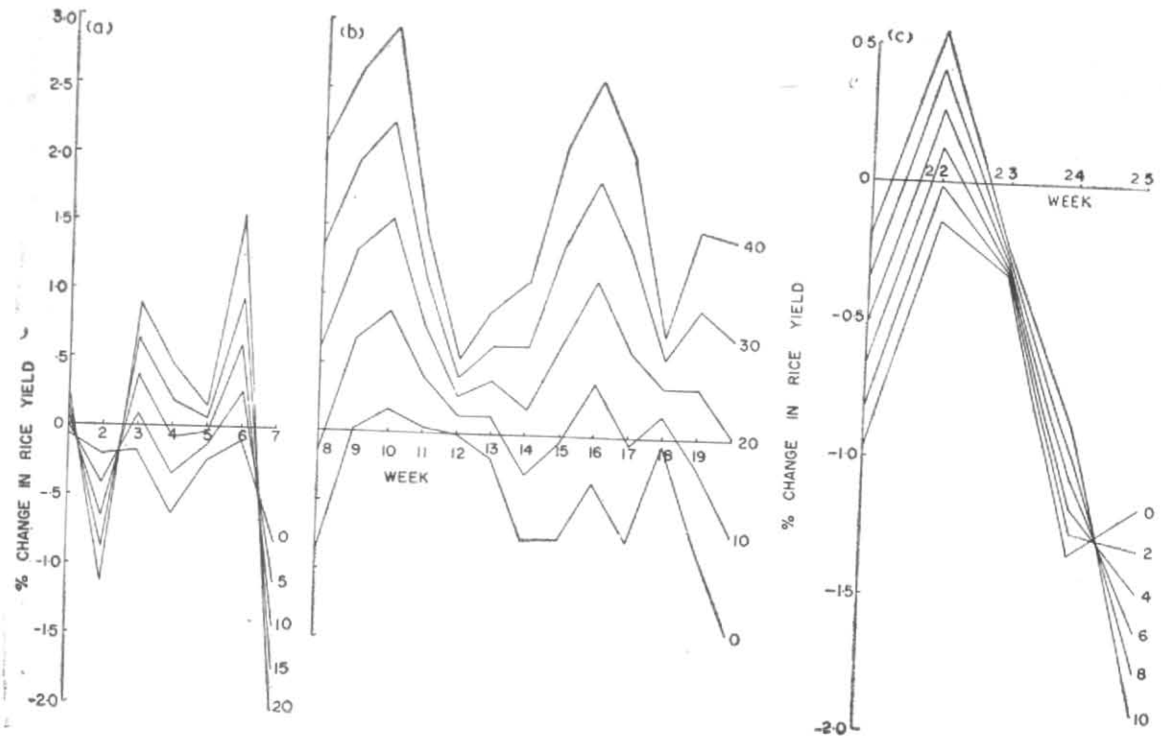


Figs. 3(a-c). Effect of 1°C above average relative humidity (14hr) on rice yield at different levels of maximum temperature during : (a) Initial growth phase, (b) Grand growth phase, (c) Ripening phase

At initial growth stage (Fig. 2 a) effects of temperature on yield have been computed for relative humidity varying from 20 to 80 per cent at an interval of 15 per cent. The small adverse effects are observed in 4th and 7th weeks and elsewhere the effects were negligible.

Effects during growth phase (Fig. 2 b) have been computed for relative humidity varying from 40 to 80 per cent at an interval of 10 per cent. Beneficial effects are observed in active vegetative phase of the crop except in the beginning of the phase. This is expected as high temperature accompanied with high humidity is good for tillering and growth of the crop. During lag vegetative and reproductive phases, small detrimental effects are observed in general. The adverse effect is pronounced in 20th week which corresponds to flowering stage of the crop. The adverse effect is of the order of 0.6 per cent for one degree rise in temperature. However, the adverse effect decreased with the rise in humidity.

During the ripening phase (Fig. 2 c), relative humidity varying from 25 to 65 per cent at an interval of 10 per cent has been considered for studying the joint effects. Adverse effects are observed in the beginning and later part of the phase. At this time high air temperature averaging approximately 30°C are not favourable (IRRI 1976) and humidity requirement is 67 to 68 per cent (FAI 1969). Since observed humidity is in the range of 57 to 38 per cent (lower than the required) and temperature 31.3 to 29.4°C (higher than the required), adverse effects due to further rise in temperature are observed. Here again, adverse effects decreased with the rise in humidity.



Figs. 4(a-c). Effect of 1°C above average maximum temperature on rice yield at different levels of rainfall during (a) Initial growth phase, (b) Grand growth phase, (c) Ripening phase

It is observed that beneficial effects of above average maximum temperature on yield increased with rise in humidity during active vegetative phase while detrimental effects decreased in other phases of crop growth. The adverse effect is pronounced during flowering stage of the crop.

3.1.2. *Effect of relative humidity at constant maximum temperature*

The rate of change of final yield with respect to humidity at any week during the growing season for different values of maximum temperature in the range 25 to 45°C at an interval of 5°C has been computed from the equation :

$$\frac{\partial Y}{\partial X_{2w}} = 0.81 \frac{r^2_{12w} X_{1w}}{\sum_{w=1}^{n} r^2_{12w}}$$

The rise in humidity has small beneficial effects in general throughout the crop season (Figs. 3 a-c). Beneficial effects are pronounced during the later part of the reproductive phase of the crop which corresponds to flowering stage. At this time sufficient moisture is required for proper seed setting. The effects increased with the increase in temperature. The beneficial effects ranged between 0.7 to 1.25 per cent for one degree increase in transformed humidity for temperature varying between 25 & 45°C.

3.2. *The joint effect of maximum temperature and rainfall*

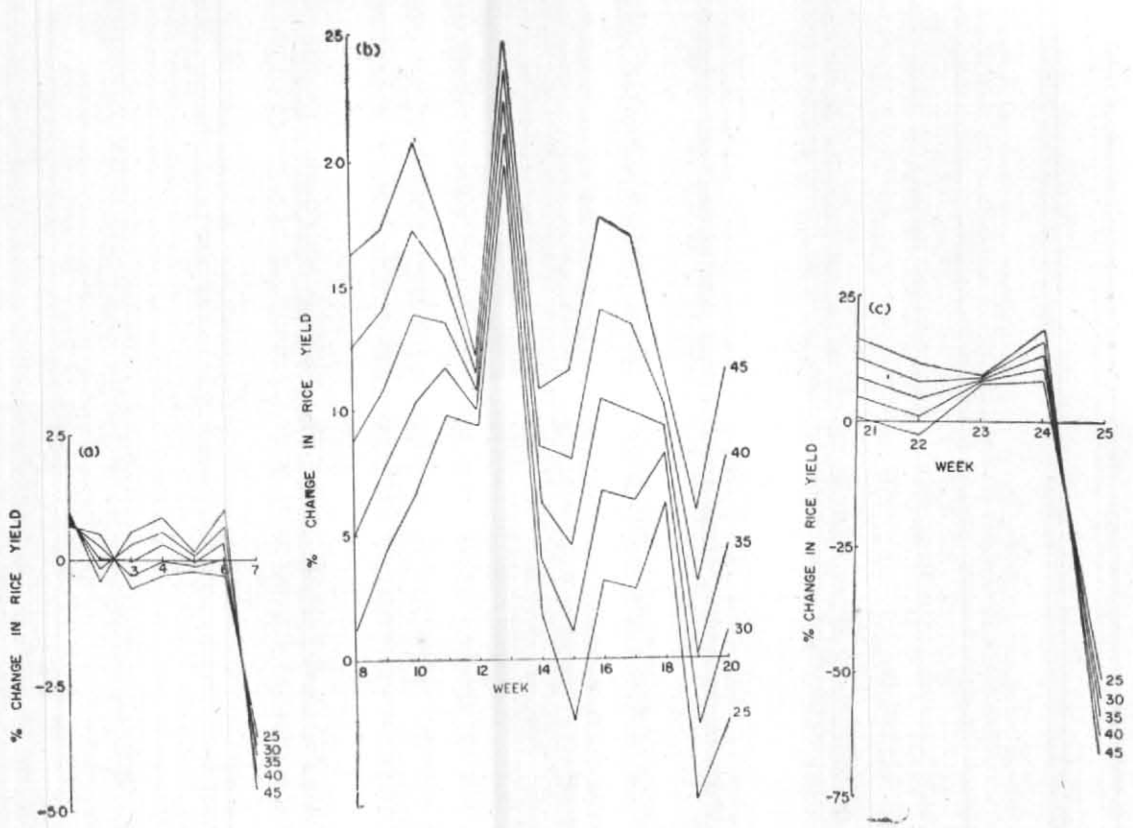
The multiple regression equation for studying the joint effects of rainfall and maximum temperature is :

$$Y = 2370.18 - 93.77\, Z_{12} + 157.84\, Z_{30} - 555.42\, Z_{31} + 255.40\, Z_{32} + 19.45\, Q_{131} - 11.49\, Q_{132} + 15.25\, T$$

The coefficient of determination (R^2), 0.71, is significant at 1 per cent level.

3.2.1. *Effect of temperature at constant rainfall*

The rate of change of final yield with respect to temperature at any week during the growing



Figs. 5 (a-c). Effect of 1 cm above average rainfall on yield at different levels of maximum temperature during (a) Initial growth phase, (b) Grand growth phase, (c) Ripening phase

season for different values of rainfall has been computed from the equation :

$$\frac{\partial Y}{\partial X_{1w}} = -93.77 \frac{r^2_{1w}}{\sum_{w=1}^{n} r^2_{1w}} + 19.45 \frac{r_{13w} X_{3w}}{\sum_{w=1}^{n} r_{13w}} - 11.49 \frac{r^2_{13w} X_{3w}}{\sum_{w=1}^{n} r^2_{13w}}$$

At initial growth phase (Fig. 4a) effects of temperature on yield have been computed for rainfall varying from 0 to 20 cm at an interval of 5 cm. The effects are detrimental in general at average rainfall observed in Raipur district. The adverse effect is of the order of 1.5 per cent at average rainfall at 7th week. The increase in rainfall has reversed the effects except towards the end of initial growth phase.

Effects during growth phase (Fig. 4 b) have been computed for rainfall varying from 0 to 40 cm at an interval of 10 cm. Rise in temperature associated with high rainfall has beneficial effects during this phase. This is expected as high temperature with more water is good for crop growth in this phase.

During ripening phase (Fig. 4c) rainfall varying from 0 to 10 cm at an interval of 2 cm has been considered. In general, adverse effects are observed. Adverse effects ranged between 0.9 and 1.4 per cent at average rainfall except in 22nd and 23rd week when the effects are small. Adverse effects decreased with increase in rainfall except in the last week of this phase.

Beneficial effects of above average maximum temperature on yield increased with increase in rainfall while adverse effects decreased in general.

3.2.2. *Effect of rainfall at constant temperature*

The rate of change of final yield with respect to rainfall at any week during the growing season for maximum temperature varying from 25 to 45° C with an interval of 5°C is obtained from the equation :

$$\frac{\partial Y}{\partial X_{3w}} = \frac{157.84}{n} - 555.42 \frac{r_{3w}}{\sum_{w=1}^{n} r_{3w}} + $$

$$+255.40 \frac{r^2_{3w}}{\sum_{w=1}^{n} r_{3w}{}^2} + 19.45 \frac{r_{13w}}{\sum_{w=1}^{n} r_{13w}} X_{1w}$$

$$- 11.49 \frac{r^2_{13w}}{\sum_{w=1}^{n} r^2_{13w}} X_{1w}$$

The increase in rainfall with sufficient temperature is beneficial for the crop except in 7th and 25th weeks which correspond to the end of initial growth and ripening phases of the crop. (Figs.5 a-c).

The study reveals that interaction among weather factors is important and should be included in the models of crop-weather relationships. The suggested model can also be used for crop forecasting by using partial crop season data.

Acknowledgements

The authors are thankful to Shri R. Gopalan and Sh. Rakesh Chandra for assistance in processing the data on computer. Authors are also thankful to the referee for his valuable comments.

References

Draper, N.R. and Smith, H., 1966, *Applied Regression Analysis*, Edn. 1, John Wiley & Sons. Inc., New York, 171-94.

Fisher, R.A., 1924, The influence of rainfall on the yield of wheat at Rothamsted. Roy. Soc. (London), *Phil. Trans. Ser. B*, **213**, 89-142, Illus.

Hendricks, W.A. and Scholl, J.C., 1943, Techniques in measuring joint relationship. The joint effects of temperature and precipitation on crop yield. N. Carolina, *Agric. Exp. Sta. Tech. Bull.*, 74.

Huda, A.K.S., Ghildyal, B.P., Tomar, V.S. and Jain, R.C., 1975, Contribution of climatic variables in predicting rice yield, *Agric. Met.*, **15**, 71-86.

International Rice Research Institute, 1976, *Climate and Rice*, Los Banos, Philippines, 175.

Jain, R.C., Agrawal, Ranjana and Jha, M.P., 1980, Effects of climatic variables on rice yield and its forecast, *Mausam*, **31**, 4, pp. 591-596.

Runge, E.C.A., 1968, Effects of rainfall and temperature interactions during growing season on crop yield, *Agron, J.*, **60**, 503-507.

Stacy, S.V., Steamson, O., Jones, L.S. and Foreman, J., 1957, Joint effects of maximum temperature and rainfall on crop yields, *Agron. J.*, **49**, 26-28.

The Fertiliser Association of India, New Delhi (1969), Rice : 5.