PREDICTING RICE YIELD FROM WEATHER VARIABLE THROUGH DETRENDED PRODUCTION INDEX

Ria Biswas[1], Banjul Bhattacharyya[1] and Saon Banerjee[2]*

[1]*Department of Agricultural Statistics, Bidhan Chandra Krishi Viswavidyalaya, Faculty of Agriculture, Mohanpur, Nadia, West Bengal*

[2]*AICRP on Agrometeorology, Directorate of Research, BCKV, Kalyani, West Bengal*

Received: 04/09/2017 | **Edited: 07/09/2017** | **Accepted: 15/09/2017**

Abstract: *Uncertainty of crop-environment including weather parameters causes a large deviation in crop yields. Reliable and timely forecast of crop yield is therefore of central importance for agricultural planners and policy makers. Weather parameters and yield forecasting are inseparably associated with each other. The present work studied the composite influences of weather variables namely, maximum temperature, rainfall and relative humidity with their interaction terms on yield of wet-season rice. Multiple regression analysis was applied to establish the combined impact of weather variables on crop yield. Using the trend value and actual production of wet-season rice the detrend production index was obtained. Higher order weather variables are generated and regression model was developed using these variables. Generated indices of weather variables along with interaction effects able to predict the variability of wet-season rice yield at district level about 82% of the total variation. Last three years data sets were utilized for model validation. The performance of the model was quite satisfactory (the accuracy level is more than 93%). Using these approaches crop yield forecasting can be done even two months before harvest.*

Key Words: *Wet-season rice, Regression model, Detrend production index, Generated weather variables, Yield.*

Introduction

Agricultural production system is largely dependent on the prevailing environment around the crop field. An understanding of the interactions between crop and weather is essential in formulating crop production strategies and yield forecasting. Reliable and timely forecasts provide important and useful key for suitable, foresighted and informed planning, very much pertinent to agriculture which is full of uncertainties. Under the changed scenario in natural environment and climatic conditions, forecasting of various aspects relating to agriculture is becoming essential. Forecasts of crop production before harvest are required for various policy decisions relating to storage, distribution, pricing, marketing, import-export, etc. (Vogel and Bange 1999). For optimum crop production interaction between the meteorological factors and the agricultural setup in an ideal condition is dreamt. It is necessary to study such effects to determine the crop yield considering the critical stages of crop life. Various approaches are available for statistical forecast modeling based on meteorological data (Baier 1977, 1979). Individual effects of weather factors on crop yield have been studied from nineteenth century (Fisher, 1924, Huda *et. al.*, 1975 and Jain *et. al.,* 1980). However, the combined effects of weather factors influence the crop yield. Hence, the joint effects of weather variables have been also studied by different scientists (Hendricks and Scholl 1943, Stacy 1975, Runge 1958).

In the present work the impact of climatic variations on wet-season rice production was estimated through regression technique. Composite effects of maximum temperature, rainfall and relative humidity with their interaction terms have been studied simultaneously to develop the suitable model. This model have used for forecasting crop yield.

Materials and Methods

Study area

The study was conducted for Nadia District (23°47' N latitude, 88°55' E longitude and 9m altitude), West Bengal, Eastern India, which falls under New Alluvial Agro-climatic Zone of West Bengal. The climate of this said zone is sub-tropical with mean annual rainfall varies from 1400 to 1700 mm. More than 70 % of total annual rainfall is received from South-West monsoon during the months of June to September. The average temperature varies from 15.6 to 35ºC. The main crop of this district is wet-season rice.

Secondary data collection

Different weather parameters and wet-season rice yield of Nadia district were utilized to develop suitable model for the period of 1981-2007. Last three years (2008-2010) data sets were utilized for model validation.

The study period was restricted from June to September i.e. the active monsoon period.

For accomplishment of this objective some meteorological parameters namely, maximum temperature, relative humidity, weekly rainfall data were collected from District Statistical Handbook (Nadia) for the period of 1981 to 2010. Yield data of wet-season rice of Nadia district were collected for the same period from the Statistical Abstracts published by the Department of Applied Economics and Statistics, Government of West Bengal.

Methodology

Production trend equations

In order to find out the impact of climatic variations on wet-season rice production in Nadia district of West Bengal, the trend component is to be removed from the original time series by fitting various trend equations such as, Linear, Quadratic, Cubic, Exponential, Power and Logarithmic.

The unknown constants were estimated by using least square technique of curve fitting. Based on R^2 and Adjusted R^2 values trend equation was used for calculating the production trend.

Detrended production index (DPI)

For estimating the detrended production the actual wet-season rice production (P) in each year during the study period (1981-2011) is expressed as a percentage of the corresponding trend value (T) to obtain the de trended production index as follows:

$$DPI= \frac{P}{T}*100 \qquad (1)$$

The DPIs are expected to be free from the technological trend and their year to year variations are assumed to be due primarily to weather.

Multiple Linear Regression (MLR) models using generated weather indices

A pioneering work has been done in crop weather relationship since early ninth century (Fisher 1924). Hendricks and Scholl (1943) modified Fisher's technique by dividing the crop season into n weekly intervals and have assumed that a second degree polynomial in week number would be sufficiently flexible to express the effect of weather on yield in successive weeks which is given by,

$$Y = A_0 + a_0 \sum_{w=1}^{n} X_w + a_1 \sum_{w=1}^{n} wX_w + a_2 \sum_{w=1}^{n} w^2 X_w + e \qquad (2)$$

where, X_w denotes value of weather variable under study in w^{th} week, n is the number of weeks in the crop season and A_0, a_0, a_1 and a_2 are the model parameters. This model was extended to study combined effects of weather variables with an additional variate T representing the year for time trend.

The model proposed by Hendricks and Scholl was further modified at IASRI and used successfully (Agrawal et al. 1980, 1983, 1986, 2001, 2005, Jain et al. 1980, Mehta et al. 2000, 2010)) in which works the effects of changes in weather variables on yield were considered as second degree polynomial in respective correlation coefficients between yield and weather variables.

The forecast model finally recommended was of the form,

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} z_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=0}^{1} a_{ii'j} z_{ii'j} + cT + e \qquad (3)$$

where, $z_{ij} = \sum_{w=1}^{m} r_{iw}{}^{j} x_{iw}$ and $z_{ii'}{}^{j} = \sum_{w=1}^{m} r_{ii'w}^{j} x_{iw} x_{i'w}$

where, r_{iw} is correlation coefficient between yield with i^{th} weather variable (Xi) $r_{ii'w}$ is correlation coefficient of yield product of i^{th} and i'^{th} weather variable ($X_{iw}X_{i'w}$) and $r_{ii'i''w}$ is correlation coefficient of yield product of i^{th} and i''^{th} weather variable($X_{iw}X_{i'w}X_{i''w}$) in w^{th} week.

Bhattacharyya and Bhowmik (2012) further modified the generated crop-weather model and used as forecast model to evaluate combined effect of weather variables on crop yield on the basis of Agrawal et al.(1983) model in which trend effect was eliminated.

The present methodology also attempted to eliminate trend effect introducing detrend production index (DPI). Again, it included the multiple effects of three weather variables at a time. So the model is further modified as follows:

$$DPI = A_0 + \sum_{i=1}^{p}\sum_{j=0}^{2} a_{ij} z_{ij} + \sum_{i\neq i'=1}^{p}\sum_{j=0}^{2} a_{ii'j} Q_{ii'j} + \sum_{i\neq i'\neq i''}^{p}\sum_{j=0}^{2} a_{ii'i''j} R_{ii'i''j} \quad (4)$$

where, DPI is the detrend production index, A_o, a_{ij}, $a_{ii'j}$, $a_{ii'i''j}$ (i = 1,2,,3, j =0, 1, 2) are unknown constants and parameters of regression model.

Z, Q and R are the first, second and third order generated weather variables which are given as follows:

$$z_{ij} = \frac{\sum_{w=1}^{n} r_{iw}^{j} X_{iw}}{\sum_{w=1}^{n} r_{iw}^{j}} \qquad Q_{ii'j} = \frac{\sum_{w=1}^{n} r_{ii'w}^{j} X_{iw} X_{i'w}}{\sum_{w=1}^{n} r_{ii'w}^{j}}$$

$$R_{ii'i''j} = \frac{\sum_{w=1}^{n} r_{ii'i''w}^{j} X_{iw}^{j} X_{i'w}^{j} X_{i''w}^{j}}{\sum_{w=1}^{n} r_{ii'i''w}^{j}}$$

where, n is the number of week.

w is the week identification (8-14th June as 1 and 21-27th September as 16)

X_{iw} = magnitude of the variables in w^{th} week.

r_{iw} = correlation of DPI with i, i.e., 1st weather variables in w^{th} week.

$r_{ii'j}$ = correlation of DPI with the product of the i and i', i.e. 1st and 2nd weather variables in w^{th} week.

$r_{ii'i''j}$ = correlation of DPI with the product of the i, i′ and i″, i.e. 1st 2nd and 3rd weather variables in w^{th} week.

In the present study, n is 16, p is 3. Weather indices were developed separately for each weather variables. Weather indices were also generated for interaction of weather variables, using weekly products taking two and also three at a time. Weather variables used for this model are maximum temperature, rainfall and relative humidity and it is considered that i refers to maximum temperature, i' refers to the rainfall and i" refers to the relative humidity.

On simplification equation (4) takes the form

$$DPI = A_0 + \sum_{i=1}^{3}\sum_{j=0}^{2} a_{ij} Z_{ij} + \sum_{i\neq i'=1}^{3}\sum_{j=0}^{2} a_{ii'j} Q_{ii'j} + \sum_{i\neq i'\neq i''=1}^{3}\sum_{j=0}^{2} a_{ii'i''j} R_{ii'i''j} \quad (5)$$

The developed model can be utilized to forecast yield by regression analysis. From equation 5 the DPI values were obtained. Fitted DPI values were originated from the correlation of DPI and generated weather parameters. The accuracy percentage of the model can be obtained from the DPI and Fitted DPI values.

Result and Discussion

Removal of Trend effect

The wet-season rice production in Nadia district of West Bengal has two distinct components namely, a) the trend component, which can be attributed to non meteorological factors such as increased grossed sown area, green revolution, improved technology and application of fertilizers, crop pest and diseases control etc. and b) the detrained production whose incremental variations are assumed primarily due to weather.

The trend equation was obtained as,

$$T = 114.586\, t^{0.289} \quad (6)$$

The R^2 value (0.831) was found to be maximum for Power equation with 0.001% level of significance. The model summary and parameter estimates are shown in Table 1. From the above power equation (6) trend values was obtained for each and every year. Using these trend values and actual production values DPI values were obtained.

Development of crop yield forecast model

Composite effects of weather variables were studied on the basis of DPI's. From the analysis of the multiple regression (Step down process) equation with composite effects of rainfall, relative humidity and maximum temperature on DPI's was obtained as,

$$\underset{(14.164)}{DPI = 44.678} + \underset{(0.071)}{0.159\, Z_{10}} + \underset{(0.202)}{0.414\, Z_{11}} - \underset{(0.015)}{9.052\, Z_{31}} + \underset{(0.172)}{7.919\, Z_{32}} - \underset{(0.001)}{0.003\, Q_{231}} - \underset{(0.008)}{0.017\, Q_{232}} - \underset{(0.010)}{0.020\, Q_{311}} + \underset{(0.003)}{0.001\, R_{1232}} \quad (7)$$

** The figures in the parenthesis indicate the std. errors.*

The above model was significant at 5% level of significance. The significant generatedweather variables to influence DPI were found as:

Z_{10}: Tmax of order one
Z_{11}: Tmax of second order
Z_{31}: RH of second order
Z_{32}: RH of third order
Q_{231}: Joint variable (RFRH) of second order
Q_{232}: Joint variable (RFRH) of third order
Q_{311}: Joint variable (RHTmax) of second order
R_{1232}: Joint variable (TmaxRFRH) of third order

where, Tmax denotes Maximum temperature, RH denotes Relative humidity and RF denotes Rainfall.

Since $R^2 = 0.815$, 82% of the variance in wet-season rice yield could be explained by all the explanatory variables The plotting between actual DPI and fitted DPI values were shown in Fig 1 which clearly indicates the performance of the model for forecast. The performance of the model is ensuring by validating the forecast model for last three years data which indicates the sufficient accuracy of the model (Table 2).

Conclusions

From this above study it can be concluded that detrended production index may be considered as a useful tool to explain the prediction model. Generated indices of weather variables along with interaction effects between the variables justify simultaneous effect of temperature, relative humidity and rainfall and are able to predict the variability of wet-season rice at district level about 82% of the total variation. The model also identifies the important weather parameters and interactions which have a significant impact to explain the model.

References

Agarwal, R., Ramkrishna, Y.S., Kesava, Rao A.V.R., Kumar, A., Bhar, L.M., Madan Mohan and Saksena, A., 2005, Modeling for forecasting of crop yield using weather parameter and agricultural inputs. (*AP Cess Fund project report*).

Agrawal, R., Jain, R.C. and Jha, M.P., 1983, Joint effects of weather variables on rice yield.*Mausam*, **34**(2): 189-194.

Agrawal, R., Jain, R.C. and Mehta, S.C., 2001, Yield forecast based on weather variables and agricultural input on agroclimatic zone basis. *Ind. J. Agri. Sci.*,**71**(7): 487-490**.**

Agrawal, R., Jain, R.C. and Singh, D., 1980, Forecasting of rice yield using climatic variables. *Ind. J. Agri. Sci.*,**50**(9): 680-684.

Agrawal, R., Jain, R.C., Jha, M.P., 1986, Models for studying rice crop-weather relationship. *Mausam,***37**(1): 67-70.

Baier, W., 1977, Crop-weather models and their use in yield assessments. WMO Tech Note 151. *World Meteorological Organization.* Geneva 1-48.

Baier, W., 1979, Note on the terminology of crop-weather models. *Agric Meteor.*,**20**: 137-145.

Bhattacharyya, B. and Bhowmik, D., 2012, Combined effect of weather variables on forecasting crop yields. *Journalof Agrometeorology,* **14**: 222-227.

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

Hendrick, 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. Stat. Tech. Bull.***74**.

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

Jain, R.C., Agarwal, R. and Jha, M.P., 1980, Effects of climatic variables on rice yield and its forecasts. *Mausam*,**31**(4): 591-596.

Mehta, S.C., Agrawal, R., Singh, V.P.N., 2000, Strategies for composite forecast. *Jour. Ind. Soc. of Agril. Stat.*,**53**(3): 362-72.

Mehta, S.C., Pal, S., Vinod, K., 2010, Weather based models for forecasting potato yield in Uttar Pradesh, *IASRI Publication.*

Runge, E.C.A. and Odell, R.T., 1958, The relation between precipitation, temperature and the yield of corn in Agronomy South Farm, Urbana, Illinois. *Agron. Jour.*,**50**: 448-454.

Stacy, S.V.,Steanson, G., Jones, L.S. and Foreman, W.J., 1957, Joint effects of maximum temperature and rainfall on corn yields, Experiment Georgia, *Agron. Jour.,***49**: 26-28.

Vogel, F., Bange, G., 1999, Understanding crop statistics (available at : www.usda.gov/nass/nassinfo/pub1554.htm.).

Table 1: Model Summary and Parameter Estimates for different models

Equation	Model Summary		Parameter Estimates		
	R^2	Constant	Sig.	b_1	b_2
Linear	0.72	158.98	1.97E^{-09}	5.39	
Quadratic	0.81	116.71	9.76E^{-11}	13.07	-0.24
Cubic	0.83	90.73	1.95E^{-10}	22.11	-0.93
Exponential	0.69	159.55	5.39E^{-09}	0.02	
Power*	0.83	114.58	1.03E^{-12}	0.28	
Logarithmic	0.79	92.69	1.60E^{-11}	60.57	

*Best fit model

Table 2: Comparison between actual DPI and forecasted DPI

Year	DPI	Forecasted DPI	Accuracy %
2008	100.34	94.56	94.24
2009	103.23	96.81	93.78
2010	98.09	97.20	99.09

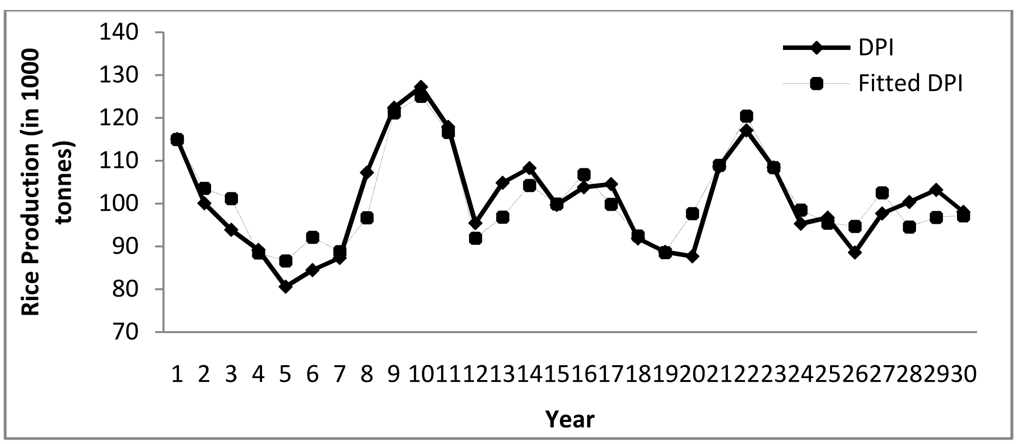

Fig 1: Plotting between DPI and fitted DPI on the basis of composite effects of maximum temperature, relative humidity and rainfall