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Use of Weather Indices Approach in Wheat Yield Crop Forecast

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ABSTRACT: *The present paper deals with use of non-linear regression analysis for developing wheat yield forecast model for Lucknow (India). In this study, trend analysis has been done through linear and non-linear approaches. In which for each weather variable two indices have been developed, one as simple total of values of weather parameter in different weeks and the other one as weighted total, weights being correlation coefficients between detrended yield and weather variable in respective weeks. Weather indices based regression models were developed using weather indices as independent variables while detrended yield (residuals) was considered as dependent variable. Time series yield data of 30 years (1971-2010) and weather data for the year 1970-71 to 2009-10 have been utilized. The models have been used to forecast yield in the subsequent three years 2008-09 to 2009-10 (which were not included in model development). The approach provided reliable yield forecast about two months before harvest.*

Keywords: *Forecasting, Nonlinear Models and Weather based regression model, Weather variables.*

INTRODUCTION

A reliable and timely forecast of crop production helps in planning, formulation and implementation of policies relating to food procurement, its distribution, price, import and export and for exercising several administrative measures for storage and marketing of agricultural commodities. Thus preharvest forecasting of production is required when crop is still standing in the field. An efficient forecasting is thus a pre-requisite for food supply information system at district and state level. The final crop production estimates, though based on objective crop-cutting experiments, are of limited utility as these become available much later after the crop harvest.

For this purpose weather based models using different statistical approaches and different types of data have been tried by the researchers. In this paper application of nonlinear regression technique has been made for modelling and forecasting yield of wheat crop for Lucknow district of Uttar Pradesh.

DATA AND CROP DESCRIPTION

District level wheat crop yield data for 40 years (1970-2010) have been collected from the Directorate of Economics and Statistics, Ministry of Agriculture, Government of India, New Delhi and from the Agriculture Directorate, Lucknow (U.P.) and India Metrological Department, Pune and CRIDA.

Weather data on temperature (maximum and minimum), relative humidity and total rainfall from the year 1970-71 to 2009-10 have been utilized for model fitting and two years data 2008-09 and 2009-10 used for validation of the model

Wheat is generally sown in the month of October when average daily temperature falls around 23-25°C. The pre-sowing phase of the crop is important because in this phase of two to three weeks, the land is prepared for the cultivation. If the weather condition is adverse during the pre-sowing phase the sowing of the crop is generally delayed. After sowing of the crop, germination takes 6-7 days or near about one week after the pre-sowing phase. After germination phase, crown root initiation occurs after 20-25 days of sowing or in about 3 weeks from germination. Tillering phase starts just after the crown root initiation phase and lasts up to 40-45 days after sowing or nearly about 2-3 weeks after crown root initiation phase. Jointing and Reproductive phase is the peak

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plant growth stage and starts after the tillering phase or 45-60 days after sowing. The reproductive phase lasts 60-85 days after sowing.

As weather during pre-sowing period is important for establishment of the crop, data starting from two weeks before sowing have been included in model development. Further, as the forecast is required well in advance of harvest, weather data about 2 months before harvesting have been considered. Thus data on four variables *viz.*, Max. temp., Min. temp., RH, Rainfall during 16 weeks data from 40th SMW to 3rd SMW (next year).

STATISTICAL METHODOLOGY

Crops yield forecast models have been developed for districts of Lucknow of U.P. state using weekly weather data. Residuals obtained from the selected non-linear models and linear models. Weather Indices (WI) were obtained using nonlinear and linear modelling approaches. Weather indices based regression models were developed using weather indices as independent variables while character under study such as crop yield was used as dependent variable for Wheat and Rice crop. Stepwise regression technique has been used for selecting significant variables in all the models.

Statistical approaches have been used for development forecast model based on weather variables, which are as follows:

NON-LINEAR REGRESSION APPROACH

There are several non-linear models which can fit different patterns in the data. The widely used non-linear models such as logistic, Gompertz, and Richards which are expected to provide a reasonable representation of crop yield as compared to linear models will be tried for fitting the yield of selected crop in a selected location using the weather data.

Logistic Model

$$Y = \frac{a}{1+\exp(b-cX)} + e$$

Where a, b and c are the unknown parameters to be estimated. e is the error.

Gompertz Model

Gompertz model is another sigmoid growth model. It is represented by

$$Y = a \exp(-\exp(b - cX)) + e$$

There are four major nonlinear estimation procedures, namely

(a) Gauss-Newton Method,

(b) Steepest-Descent Method,

(c) Levenberg-Merquadt Technique and

(d) Do Not Use Derivative (DUD) Method.

Either Gauss-Newton Method (the most widely used and reliable procedure for computing nonlinear least square estimates) .

The residuals from above model will be used in the subsequent linear model for fitting against different forms of the weather variables including their indices. The weather variables within an agricultural year will be aggregated through mean or through indices as mentioned above. Further, indices will be computed based on the influence (positive or negative) of the selected weather variable on the crop yield.

WEATHER INDICES APPROACH

For each weather variable, two indices will be developed, one as simple total of values of weather variables parameter in different weeks and the other one as weighted total, weights being correlation coefficients between detrended yield and weather variable in respective weeks. The first index represents the total amount of weather parameter received by the crop during the period under consideration. While the other one takes care of distribution of weather parameters with special reference to its importance in different weeks in relation to the detrended yield. On Similar line, indices were computed with products of weather variables (taken two at a time) for joint effects.

These indices are computed as follows:

$$y = a_0 + \sum_{i=1}^{p}\sum_{j=1}^{1} a_{ij} Z_{ij} + \sum_{i\neq i'=1}^{p}\sum_{j=0}^{1} b_{ii'} Z_{ii'j} + \varepsilon$$

$$Z = \sum_{w=n1}^{n_2} r_{iw}^{j} X_{iw}$$

$$Z_{ii'j} = \sum_{w=n1}^{n_2} r_{ii'w}^{j} X_{iw} X_{i'w}$$

where,

y is detrended yield forecast,

X_{iw} is value of i^{th} weather variable in w^{th} week

r_{iw} is correlation coefficient between Y and i^{th} weather variable in w^{th} week, *i.e.* X_{iw}

$r_{ii'w}$ is correlation coefficient between Y and product of X_{iw} and $X_{i'w}$ in w^{th} week,

p is number of weather variables,

n_1 is initial week for which weather data are included in the model,

n_2 is final week for which weather data are included in the model and

a_{ij} *and* $b_{ii'}$ are parameters to be estimated

ε is the random error

Stepwise regression technique was used for retaining significant variables only in the forecast models in each approach.

COMPARISON AND VALIDATION OF MODELS

Different regression models were compared on the basis of adjusted efficient of determination (R^2_{adj}) which is as follows:

$$R^2_{adj} = 1 - \frac{ss_{res}/(n-p)}{ss_t/(n-1)}$$

where $ss_{res}/(n-p)$ is the residual mean square and $ss_t/(n-1)$ is the total mean square.

From the fitted models, wheat yield forecasts for the years 2008-09 to 2009-10 were obtained and forecasts were compared with the actual yield on the basis of Root Mean Square Deviation (RMSE).

$$RMSE = \left[\left\{\frac{1}{n}\sum_{i=1}^{n}(O_i - E_i)^2\right\}\right]^{\frac{1}{2}}$$

where O_i and the E_i are the observed and forecast value of crop yield respectively and n is the number of years for which forecasting has been done.

RESULT AND DISCUSSION

The two step nonlinear forecasting model was found to be superior or at far to the linear model as its RMSE value (2.05) is much lower as compared that of linear model (2.37). For fitting this residual model the nonlinear model (Logistic) which was found to have better fit was used to output the residuals. The negative values of the coefficients for variables such as Z131 (max tem*rainfall), showed that increase in the variables results in decrease in the yield. On the other hand variable such as Z21 (min) and Z341 (rainfall* relative humidity) yielded positive coefficients which means that increase in the variables will increase the yield of wheat crop in Lucknow district of Uttar Pradesh. Similarly, RMSE values are much lower as compared that of linear model in Lucknow districts of UP, thereby showing that two step nonlinear forecasting models were found to be superior for yield forecasting of wheat crop. The models provides reliable forecast around two months before harvest.

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Table: 1
Lucknow Wheat Yield Forecast Models (Two Steps Non-Linear & Linear Models) Based on Weather Indices Approach

District Name	*Forecasting Model*	*Goodness of fit*	
		Adj R^2	*RMSE*
Lucknow			
Non-linear	$Yt = 0.48 + \underset{(0.46)}{0.74}Z21 - \underset{(0.019)}{0.058}Z131 + \underset{(0.006)}{0.016}Z341$	0.91	2.05
Linear	$Yt = -0.22 + \underset{(0.093)}{0.15}Z11 + \underset{(0..043)}{0.85}Z21 - \underset{(0.016)}{0.064}Z131 + \underset{(0.006)}{0.012}Z341$	0.89	2.37

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