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Weather based yield crop forecasting: Agro-Physics Approach

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The present paper deals with use of non-linear regression analysis for developing Wheat yield forecast model for Jhansi (India). 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 Crop i.e. two step non-linear forecast model. Technique of forecasting using non-linear approach and using weather indices will enrich the knowledge in developing customized models on forecasting for different types of crops and for different locations. For that, 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 40 years (1970-2010) 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 regression model, Weather Indices Approach**,** Weather variables.

1. INTRODUCTION

Reliable and timely forecast provide important and useful input for proper, foresight and informed planning, more so, in agriculture which is full of uncertainties. Due to uncertainties of weather, government policies relating to price, etc. often lead to losses to farmers. Agriculture now-a-days has become highly input and cost intensive. Without judicious use of fertilizers and plant protection measures, agriculture no longer remains as profitable as before. The policy planners and farmers need reliable forecast of crop yield when the crop is still standing in the fields. Thus, there is need to develop an efficient system of forecasting crop yield. Agrawal *et al.* [1] showed that crop yield is influenced by technological change and weather variability. Technological factors increase yield smoothly through time and, therefore, years or some other parameters of time can be used to study the overall effect of technology on yield. Thus pre-harvest forecasting of production is required when crop is still standing in the field [2]. An efficient forecasting is thus a pre-requisite for food supply information system at district and state level. Panwar *et al.* [3,4] gave 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. It is of high importance that with the advancements in non-

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linear estimation techniques and high computational ability to try for non-linear modeling of yield forecast using different weather parameters and using their indices.

In this paper application of nonlinear regression technique has been made for modelling and forecasting yield of wheat crop for Jhansi district of Uttar Pradesh.

2. 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 & 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 & 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 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 40^{th} SMW to 3^{rd} SMW (next year).

3. STATISTICAL METHODOLOGY

Crops yield forecast models have been developed for districts of Jhansi 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 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:

3.1. Non-Linear Models

Following nonlinear growth models will provide a reasonable representation of yields 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 $$Y = \frac{a}{1 + \exp(b - ct)} + e$$

Gompertz Model: $$Y = a\exp(-\exp(b - ct)) + e$$

Richards Model: $$Y = \frac{a}{1 + \exp(b - ct)^{1/d}} + e$$

Weibull Model: $$Y = a - b\exp(-ct^{d}) + e$$

Where a, b, c and d are the unknown parameters to be estimated.

For nonlinear estimation procedures, Gauss-Newton Method is used by Seber and wild [5] which yields efficient estimates with proper convergence was applied in this study as shown in Table 1.

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.

3.2. 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:

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

$$Z_{ij} = \sum_{w=n_1}^{n_2} r_{iw}^{j} X_{iw}$$

$$Z_{ii'j} = \sum_{w=n_1}^{n_2} r_{ii'w}^{j} X_{iw} X_{i'w}$$

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,

$r_{ii'w}$ 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} & $b_{ii'}$ 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.

3.3. Comparison and Validation of Models

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

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

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).

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

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.

Table 1: Comparison of fitted Linear and different Non-linear Models for data on Jhansi District of U P of Wheat yield

Parameters /Statistics	**Jhansi (Wheat)**			
	Linear	Logistic	Gompertz	Mono-molecular
a	8.26	30.04	35.94	80.54
b	0.46	1.04	0.42	7.72
c		0.07	0.03	0.007
Goodness of Fit Statistics				
R^2	0.82	0.84	0.84	0.83
MSE	5.49	4.96	5.19	5.43
RMSE	2.34	2.22	2.27	2.33
MAE	1.74	1.66	1.69	1.73
MAPE	11.50	11.02	11.29	11.62
Theil statistics	0.01	0.23	0.09	0.017

Table 2: Jhansi Wheat Yield Forecast Models (Two Steps Non-Linear & Linear Models) Based on Weather Indices Approach

District Name	**Forecasting Model**	**Goodness of fit**	
		R^2	**RMSE**
Jhansi Non-linear	$Yt = -18.48 + \underset{(0.09)}{0.51} Z11 + \underset{(0.37)}{0.81} Z31 - \underset{(00.012)}{0.026} Z131 + \underset{(0.0069)}{0.016} Z231$	0.98	1.79
Linear	$Yt = -18.63 + \underset{(0.17)}{0.5} Z11 + \underset{(0..33)}{0.81} Z31 + \underset{(0.006)}{0.015} Z231 - \underset{(0.0008)}{0.0038} Z341$	0.90	2.21

Table 3: MAPE of Forecast of Wheat Yield from models developed.

Districts	Two step nonlinear models	Linear models
Jhansi	8.52	9.54

4. 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 (1.79) is much lower as compared that of linear model (2.21). For fitting this residual model the nonlinear model (Logistic) which was found to have better fit was used to output the residuals. The values of the coefficients for variables such as Z31 (rainfall) and Z231 (min temp*rainfall), showed that increase in the variables results in decrease in the yield. On the other hand, variable such as Z11 (max temp) and Z231 (max temp*relative humidity) yielded positive coefficients which means that increase in the variables will increase the yield of Wheat crop in Jhansi district of Uttar Pradesh as in Table 2. Similarly, RMSE values are much lower as compared that of linear model in Jhansi districts of UP, thereby showing that two step nonlinear forecasting models were found to be superior or at par for yield forecasting of Wheat crop. The models provide reliable forecast around two months before harvest, and MAPE shows that two step no linear model provide better results as shown in Table 3.

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