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Mathematical Modelling of Crop Yield Forecasting and Forewarning of Pests/Diseases

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Abstract

A full-fledged algorithm for performing statistical forecasting and estimating the agricultural yield for a variety of Rabi and Kharif crops has been developed. A model for forecasting of crop yield based on historical data and pertinent external climatic information was developed. The technique included development of suitable weather indices which were used as regressors in the model, determining their suitable weights for the true determination and minimizing the error term.

Apart from the crop produce, pests and diseases, major factors limiting the production, are also influenced by weather conditions. Therefore, an ordinal logistic model was developed for forewarning of important pests/diseases in rice, mustard, pigeon pea, sugarcane, groundnut, mango, sugarcane, cauliflower, sorghum, banana, citrus, soyabean and cotton at various locations. The forewarnings through these models can prove to very useful in taking timely control measures. Finally, to facilitate a graphical user interface for the rural community, a windows based application was developed for the same.

Subject Classification: MSC Primary 62-07

1. Introduction

Rural Community is faced with the challenge of their basic survival. India, being an agro-based economy, depends heavily upon the gains it incurs from its rural masses. This calls for the need to develop rural people at various fronts – Agriculture, Education and Healthcare.

Well-timed and accurate forecasts of crop production can be quite helpful in policy making for storage, distribution, pricing, marketing, import-export etc. [1]. To a large extent, Crop Produce is affected by a variety of pests and diseases. This allows for unseen yield-losses which can be prevented or at least controlled with some prior knowledge of the time and severity of the outbreak of these diseases. Thus, it is imperative to look into the various factors that affect crop yield and infestation of pests and diseases. Weather is one of the most crucial factors that can help provide reliable prediction of crop yield and govern the attack of pests. In this paper, a weather-indices based model of crop yield forecasting and an ordinal logistic regression model for forewarning have been proposed that provide sufficient and timely crop protection.

Further, a Windows-based App has been created that provides a single platform to the farmer to view Crop Yield Estimation, Probability of occurrence of a particular Disease and nearby educational institutions and healthcare facilities which would in-turn help raise the living standards of the people. A variety of other widgets such as various Government Policies like MNREGA etc., Helpline numbers, Profit Estimation, Water Quality Monitoring and Video tutorials for farmers aid in the task of developing the rural community.

2. Yield Forecast Model

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A variety of Weather-Indices based Models have been proposed till date, which provide far from satisfactory forecasts. Such models utilise data on yield and weather variables for past several years pertaining to location(s) under consideration. Crop yield is majorly affected by weather variability, the trend of which can prove to be useful in making reliable predictions. The weather variability both within and between seasons is an uncontrollable source of variability in yield. The weather variables affect the crop differently during various stages of development. Thus, extent of weather influence on crop yield depends not only on the magnitude but also on the distribution pattern of weather variables over the crop season which, as such, calls for the necessity of dividing the whole crop season into fine intervals [1].

The following aspects were considered in developing yield forecast methodology:

i) Data Collection
ii) Choice of weather variables and their measurement
iii) Method of statistical analysis and development of forecast model
iv) Adoption of developed technique to our existing system

2.1 Data Collection

Secondary data pertaining to Crop Yields for a few crops was collected for the years 2000-2011 for the following states –

Andhra Pradesh, Arunachal Pradesh, Bihar, Gujarat, Kerala, Maharashtra, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal.

Major Cropping season in India include:

i) Kharif Crops: These are domesticated plants cultivated and harvested during the rainy (monsoon) season in the

South Asia, which lasts between April and October depending on the area.

ii) Rabi Crops: These agricultural crops are sown in winter and harvested in the spring.

Crops considered were classified based on the type of growing season as shown.

Table: 1. List of Kharif and Rabi Crops under consideration

Kharif Crops	Rabi Crops
Rice, Sugarcane, Pulses, Cotton	Wheat, Oilseeds, Food Grains, Coarse Cereals

2.2 Choice of Weather Variables

Of the several weather factors that affect the Crop Yield, three major factors were chosen and secondary data was collected manually for the above mentioned states. The following were the chosen factors:

X1: Maximum Temperature
X2: Minimum Temperature
X3: Humidity

2.3 Statistical Analysis and Development of Model

A lot of Weather-Indices based Models are currently employed in the field of Crop Yield Forecasting. However, they are limited in terms of predictability accuracies. Considering the inter-correlated values of the various weather parameters chosen, a statistical model based on correlation of various factors was proposed as shown:

Yield Statistics:

Proposed formula:

$$Y_{est} = \sum_{i=1}^{l} [a_{i_0}(Z_0)_i + a_{i_1}(Z_1)_i + a_{i_2}(Z_2)_i] + \varepsilon \quad (1)$$

Where n = no. of months, l = no. of weather variables.

And

$$(Z_0)_i = \frac{(\sum_{i=1}^{n} W_{i_k})}{n}, (Z_1)_i = \frac{\sum_{k=1}^{n} \rho_k W_{i_k}}{\sum_{k=1}^{n} \rho_k}, (Z_2)_i = \frac{\sum_{k=1}^{n} \rho_k^2 W_{i_k}}{\sum_{k=1}^{n} \rho_k^2}, \quad (2)$$

Our Version:

$$Y_{est} = \sum_{i=1}^{3} [a_{i_0}(Z_0)_i + a_{i_1}(Z_1)_i +] + \varepsilon \quad (3)$$

Where n is the no. of months = 5 or 4
Here,

$$(Z_0)_i = \frac{(\sum_{i=1}^{5,4} W_{i_k})}{5,4}, (Z_1)_i = \frac{\sum_{k=1}^{5,4} \rho_k W_{i_k}}{\sum_{k=1}^{5,4} \rho_k}, \quad (4)$$

Here, W (i)'s denote the various regression parameters taken into consideration.

The detailed schema of the model has been described below.

3. Forewarning Against Pests and Diseases

The timely control measures to prevent pest/ disease outbreak can be taken even if the information on the extent of severity is not available but merely the epidemic status is accessible. This information could be obtained through modeling qualitative data. Such models have added advantage that these could be obtained even if the detailed and exact information on pest count/disease severity is not available but only the qualitative status such as epidemic or no epidemic / low, medium or high is known. Such a situation arises quite often in pest/disease data.

The technique was applied for forecasting epidemic status of Alternaria blight & White rust (Mustard), Whitefly (Cotton), Pyrilla (Sugarcane) and Powdery mildew & Fruit fly (Mango).

3.1 Data Collection

Secondary data pertaining to outbreak of pests/diseases for the following crops was collected for the years 1987-2012:

Table: 2. Sample List of Crops with Pests/Diseases under Consideration

Region	Crop	Pest/Disease
Lucknow	Mango	Powdery Mildew
Gorakhpur	Sugarcane	Pyrilla
Ghaziabad, Merut, Agra, Moradabad	Sugarcane	White grub
Aligarh	Cauliflower	Diamond back moth
Alwar, Churu	Sorghum	Grasshopper
Karoli, Sirohi, Bikaner	Gram	Gram Pod borer
Sriganganagar	Cotton	Mealy bug
Sriganganagar	Gram	Gram pod borer

3.2 Choice of Weather Variables

Of the several weather factors that lead to the outbreak of Pests and Diseases, two major factors were chosen and secondary data was collected manually for the above mentioned regions. The following were the chosen factors:

X1: Maximum Temperature
X2: Minimum Temperature

3.3 Ordinal Logistic Model for Pest Forewarning

Ordinal logistic models were developed to forecast probability of occurrence (Y=1) / non-occurrence (Y=0) of the pest/disease. In cases where the data were in quantitative form, the same were converted to dichotomous form using threshold values.

The form of the model was:

$P(Y=1) = 1/1+\exp(-L)$ (5)

Where $L = \sum \beta i\, Xi$

Xi: weather variables/weather indices.

$P < 0.5$ indicates that the probability of epidemic occurrence will be minimal.

P □ 0.5 indicates that there is more chance of occurrence of epidemic.

Different combinations of weather variables (maximum & minimum temperature, relative humidity (morning & evening) and mean relative humidity), along with their interactions, were tried in construction of function L. The combination that provided most of the prediction probabilities matching with the observed ones was identified.

4. Results & Conclusion

4.1 Crop Yield Forecast

Yield estimates for various enlisted crops was successfully achieved with high amount of accuracies based upon the proposed model. The yield per hectare can be easily used to compute the approximate total crop yield which can act as a reliable estimator of the actual crop produce. This value can be further used by the farmer to foresee attached profits/losses and act accordingly in order to maximize the gains.

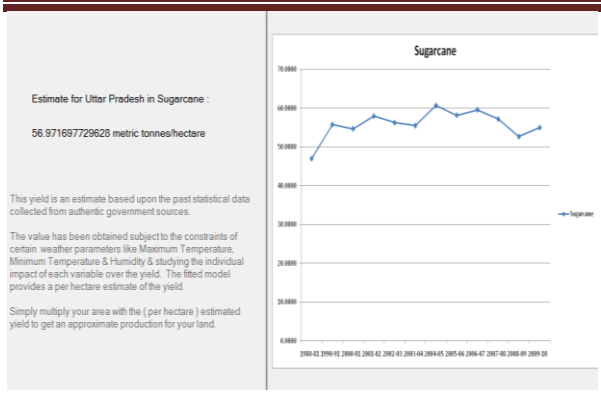

Fig: 1. Crop yield forecast for sugarcane in U.P.

4.2 Forewarning of Pests/Diseases

Successful forewarning against pests/diseases was performed using the ordinal logistic regression model. The results matched with the actual occurrence/non-occurrence of pests and diseases of various crops.

(a) App Section for Forewarning

(b) Requisite probability of occurrence of Pest/Disease

Fig: 2. Guidelines for Forewarning Against Pest/Diseases

A windows based application was designed to implement the above models for crop yield prediction and pest forewarning system respectively.

References

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