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Weather Based Forecasting of Crop Yields, Pests and Diseases – IASRI Models

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SUMMARY

In view of the fact that weather affects crops, several weather based models have been attempted for forecasting crop yield for various crops at selected districts/agro climatic zones/states. The models utilised weekly/fortnightly weather data and, in some cases, agricultural inputs at district level. The techniques included development of suitable weather indices which were used as regressors in the models, discriminant function analysis and water balance technique. Using these approaches, reliable forecast of crop yield can be provided before harvest - 2½ months (rice and wheat), 1½ month (sorghum), 1 month (maize) and in middle of September in sugarcane. Pests and diseases, major factors limiting the production, are also influenced by weather conditions. Therefore, weather based models were developed for forewarning of important pests/diseases in rice, mustard, pigeon pea, sugarcane, groundnut, mango, potato and cotton at various locations using the techniques like regression analysis (taking suitable functions of weather variables/indices as regressors), complex polynomials through GMDH technique and Artificial Neural Network technique. The forewarnings through these models will be very useful in taking timely control measures. These approaches have been successfully used by other workers and organisations for forecasting crop yield and the forewarnings issued enabled the farmers to optimise plant protection measures. In this paper various approaches are discussed with illustrations.

Key words : Yield forecast models, Pests and diseases, Composite weather variables, Ordinal logistic model, GMDH technique, ANN.

1. INTRODUCTION

Reliable and well-timed forecasts are of vital importance for appropriate, foresighted and up-to-date planning especially for agriculture which is full of uncertainties. In crops, production and attack of pests/ diseases are the two key aspects which necessitate forethought. Forecasts of crop production (before harvest) are required for various policy decisions relating to storage, distribution, pricing, marketing, import-export etc. Pests and diseases are the foremost causes of reduction in crop yield. To reduce the yield-loss, timely application of remedial measures is essential which is feasible with prior knowledge of the time and severity of the outbreak of pests and diseases. Thus, factors affecting crop yield and infestation of pest and diseases need to be looked in to. Weather plays an important role in crop growth as well as development of pests and diseases. Therefore, models based on weather parameters can provide reliable forecast of crop yield in advance of harvest and also forewarning of pests and diseases attack so that suitable plant protection measures could be taken up timely to protect the crops. A number of techniques have been developed at Indian Agricultural Statistics Research Institute for various crops. In the present paper, some of the models are discussed.

2. YIELD FORECAST MODELS

Models utilised data on yield and weather variables for past several years pertaining to location(s) under consideration. Crop yield in different years is affected by technological change and weather variability. It can be assumed that the technological factors will increase yield smoothly through time and therefore, year-number (or some other appropriate function of time) can be used to study the overall effect of technology on yield. The weather variability both within and between seasons is another 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. This will increase number of variables in the model and in turn a large number of model parameters will have to be evaluated from the data. This will require a long series of data for precise estimation of parameters which may not be available in practice. Thus, a technique based on relatively smaller number of manageable variables and at the same time taking care of entire weather distribution may solve the problem. In this reference various studies conducted so far are discussed below :

2.1 Models using Composite Weather Variables

Fisher (1924) and Hendricks and Scholl (1943) have suggested models which require small number of parameters to be estimated while taking care of distribution pattern of weather over the crop season.

Fisher utilised weekly weather data. He assumed that the effect of change in weather variable in successive weeks would not be abrupt or erratic but an orderly one that follows some mathematical law. He assumed that these effects as well as magnitude of the variable in successive weeks are composed of the terms of a polynomial function of time. Substituting these in usual regression equation

$$Y = A_0 + A_1X_1 + A_2X_2 + ... + A_nX_n + e$$

where Y denotes yield and X_w rainfall in w-th week w = 1, 2,..., n and utilising the properties of orthogonal and normalised functions, he obtained

$$Y = A_0 + a_0\,\rho_0 + a_1\,\rho_1 + a_2\,\rho_2 + ... + a_k\,\rho_k + e$$

where $A_0, a_0, a_1, a_2, ... a_k$ are parameters to be determined and ρ_i (i = 1,...k) are distribution constants of X_w and e is error term. Fisher has suggested to use k = 5 for most of the practical situations. In fitting this equation for k = 5, the number of parameters to be evaluated will remain 7, no matter how finely growing season is divided. This model was used by Fisher for studying the influence of rainfall on the yield of wheat.

Hendricks and Scholl (1943) modified Fisher's technique. They assumed that a second degree polynomial in week number would be sufficiently flexible to express the effects in successive weeks. Under this assumption, the model suggested by Hendricks and Scholl is

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

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 model parameters.

In this model number of parameters to be determined reduced to 4, irrespective of n. This model was extended to study joint effects of weather variables and an additional variate T representing the year was included to make allowance for time trend.

At Indian Agricultural Statistics Research Institute, the model suggested by Hendricks and Scholl has been modified by expressing effects of changes in weather variables on yield in the wth week as second degree polynomial in respective correlation coefficients between yield and weather variables (Agrawal *et al.* 1980, 1983; Agrawal and Jain 1982 and Jain *et al.* 1980). This is expected to explain the relationship in a better way as it gives appropriate weightage to weather in different weeks. Under this assumption, the models were developed for studying the effects of weather variables on yield using complete crop season data whereas forecast model utilised partial crop season data. These models were found to be better than the one suggested by Hendricks and Scholl.

These models were further modified (Agrawal *et al.* 1986) by expressing the effects of changes in weather variables on yield in wth week as a linear function of respective correlation coefficients between yield and weather variables. As trend effect on yield was found to be significant, its effect was removed from yield while calculating correlation coefficients of yield with weather variables to be used as weights. Effects of second degree terms of weather variables were also studied. The results indicated that (i) the models using correlation coefficients based on yield adjusted for trend effect were better than the ones using simple correlations and (ii) inclusion of quadratic terms of weather variables and also the second power of correlation coefficients did not improve the model. This suggested the use of following type of model to study effects of weather on yield.

$$Y = A_0 + a_0\,Z_0 + a_1\,Z_1 + c\,T + e$$

$$\text{where} \quad Z_j = \sum_{w=1}^{n} r_w^j\,X_w \qquad j = 0, 1$$

where Y is yield, r_w is correlation coefficient of weather variable in w-th week (X_w) with yield (adjusted for trend effect, if present) and e is error term. The model was further extended for studying joint effects.

The forecast model has been developed using partial crop season data considering all weather variables simultaneously. The model finally recommended was of the form

$$Y = A_0 + \sum_{i=1}^{p} \sum_{j=0}^{1} a_{ij} Z_{ij} + \sum_{i \neq i'=1}^{p} \sum_{j=0}^{1} a_{ii'j} Z_{ii'j} + cT + e$$

where

$$Z_{ij} = \sum_{w=1}^{m} r_{iw}^{j} X_{iw} \text{ and } Z_{ii'j} = \sum_{w=1}^{m} r_{ii'w}^{j} X_{iw} X_{i'w}$$

$r_{iw}/r_{ii'w}$ is correlation coefficient of yield (adjusted for trend effect, if present) with ith weather variable/product of ith and i'th weather variables in wth week, m is week of forecast and p is number of weather variables used.

In this model, for each weather variable, two weather indices were developed, one as simple accumulation of weather variable and the other one as weighted accumulation of weekly weather variable, weights being correlation coefficients of weather variable in respective weeks with yield (adjusted for trend effect, if present). Similarly, for interaction of weather variables, indices were generated using weekly products of weather variables taking two at a time. Stepwise regression technique was used to select the important weather indices.

The above approach was used to forecast yield of rice and wheat at district level in different situations, viz. (i) rainfed district having deficient rainfall (rice), (ii) rainfed district having adequate rainfall (rice) and (iii) irrigated district (wheat). Data starting a fortnight before sowing were considered as this period is expected to have effect on establishment of the crop. The results revealed that reliable forecasts can be obtained when the crops are 10-12 weeks old i.e. about 2 to 2½ months before harvest. This approach was also used to develop forecast model for sugarcane for Kohlapur district using fortnightly weather data (Mehta *et al.* 2000). Deviations of forecasts for subsequent years (not included in model development) from observed ones ranged between 5-10%.

These studies, carried out at district level, revealed data requirement of about 25 years for reliable forecasts. Such a long series may not be available for most of the locations. Therefore, model development was attempted at agro climatic zone level. The models were developed by pooling the data of various districts within the zone so that a long series could be obtained in a relatively shorter period. Models were developed for wheat in Vindhya Plateau zone and for rice in Chattisgarh Plain & Bastar Plateau zone taken together (as a portion of Bastar district falls under Chattisgarh Plain zone whereas remaining under Bastar Plateau zone and yield figures were available at district level only). Agricultural inputs, previous year's yield and moving averages of yield were taken as the variables taking care of variation between districts within the zone. Year was included to take care of technological changes. Different strategies for pooling district level data for the zone were adopted. Results revealed that reliable forecasts can be obtained using this methodology at 12 weeks after sowing i.e. about 2 months before harvest at zone level also. The data requirement reduced to 10-15 years as against 25 years (approx.) for district level models. The study also revealed that forecast model will be appropriate to forecast the yield of a zone even if data for some districts within the zone are not available at model development stage or at forecasting stage (Agrawal *et al.* 2001).

This approach was further studied in detail for various districts and agro climatic zones of Uttar Pradesh for one major kharif crop (rice), one major rabi crop (wheat) and one long duration crop (sugarcane) so as to come out with a suitable methodology for forecasting crop yields at state level. It was observed that performance of the models based on only weighted indices was almost at par with those developed earlier. Therefore, the simplified form of the model based on only weighted weather indices has been recommended. With this approach, reliable forecasts for rice and wheat could be obtained when crop was 11 weeks old i.e. approx. 2« months before harvest. Sugarcane forecast could be obtained in the middle of September using data of 14 fortnights (starting from March first fortnight). The forecasts for subsequent years were compared with two types of observed yields - one based on the districts for which forecasts were obtained while the other one based on all districts of the state. The results are presented in Table 1.

Table 1. Forecasts for rice, wheat and sugarcane in Uttar Pradesh

Observed yield based on	Percent deviation of forecasts from observed yield		
	Rice	Wheat	Sugarcane
Districts used in forecasts	4.2	0.7	0.8
All districts of U.P.	3.3	4.3	4.5

The methodology is simple, adoptable, does not involve use of very detailed data collection/sophisticated statistical tools and at the same time provides reasonably good forecasts. It is suitable at district, agro climatic zone as well as state level. This approach has been used by Space Applications Centre, Ahmedabad to obtain forecast for wheat yield at national level. The forecast, thus, obtained was with only 3% deviation from observed yield.

2.2 Model using Discriminant Function Analysis

At district level, model based on time series data of weather variables was also developed using technique of discriminant function analysis. The long series data of 25–30 years was classified into three groups – congenial, normal and adverse on the basis of crop yield. Using weather data of these groups, linear and quadratic discriminant functions were fitted. These functions were used to find weather scores for each year at different phases of crop growth which were used as regressors in forecast model along with agricultural inputs and time trend. The study has been carried out for rice in Raipur district. The performance of quadratic discriminant function was found to be better than linear discriminant function. This might be due to heterogeneity in dispersion matrices of weather variables in different groups. This approach could provide reliable yield forecast, with approx. 1% deviation from actual observed yield, about two months before harvest (Rai and Chandrahas 2000).

2.3 Models using Water Balance Technique

Using water balance technique, models have been developed for rainfed crops, rice (Raipur), sorghum (Delhi and Parbhani) and maize (Delhi). In this approach, water deficit/surplus was worked out at weekly intervals. Weighted stress indices were prepared phase-wise by applying appropriate weights to surplus as well as deficit depending upon stage at which it occurred. These stress indices for each year were used as regressors along with time trend to develop the forecast model.

The estimated soil moisture in the root zone at the end of i-th week was obtained from the relation

$$S_i = S_{i-1} + R_i - WR_i$$

where R_i = rainfall in the i-th week

WR_i = water requirement of the crop in i-th week $= k_i \times$ evapi

(k_i is crop coefficient and evapi is pan evaporation in the i-th week)

Stress due to deficit, St_i = 1 ? AE_i / WR_i, where AEi is actual evapotranspiration.

Stress due to water surplus was taken as '1' if S_i > water holding capacity.

Using this technique the forecasts were obtained for sorghum, maize and rice respectively 6, 4 and 5 weeks before harvest. Deviations of forecasts from observed yields for subsequent years ranged between 1?11% (Saksena *et al.* 2001).

3. FOREWARNING OF PESTS AND DISEASES

Forewarning of pests and diseases are required for taking timely action regarding pests and diseases control and for assessing losses. However, timely control measures can be taken even if the information on pest population/disease severity is not available but merely their 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 pests/diseases data. In this paper, models based on both qualitative as well as quantitative data are discussed.

3.1 Model for Qualitative Data - Ordinal Logistic Model

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

The form of the model was

$$P(Y=1) = \frac{1}{1+exp(-L)} + e$$

where $L = \beta 0 + \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n$; $X_1, X_2, X_3 ... X_n$ are weather variables/weather indices and e is random error.

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.

The results of fitting of above model in different cases are presented in Table 2.

(Agrawal *et al.* 2004, Ramasubramanian, V. 2002 and Mehta *et al.* 2001)

Table 2. Forecasting outbreak of pests and diseases using Ordinal Logistic model

Crop (Location)	Pest / Disease	Important variables	Time of Severity	Time of Forecast
Mustard (Hissar)	Alternaria blight	MINT, RH1 & RHII	Feb.	Mid Dec.
	White rust	MAXT, MINT & RH1	Feb.	Mid Dec.
Cotton (Lam)	White fly	MAXT, MINT, RH1 & RHII	Mid Dec.	Mid Nov.
Sugarcane (Muzaffar nagar)	Pyrilla	MAXT & RHM	Oct.-Nov.	May
Mango (Lucknow)	Powdery mildew	MAXT, MINT & RH1	May-June	3rd week of March
	Fruit fly	MAXT, MINT & RH1	May-June	2nd week of March

Note : MAXT = maximum temperature, MINT = minimum temperature, RH1= relative humidity (morning), RHII = relative humidity (evening) and RHM = mean relative humidity

3.2 Models based on Quantitative Data

Models were developed for forewarning time of first appearance of disease or pest, time of maximum disease severity/pest population, maximum disease severity/pest population and age-wise/standard meteorological week-wise or year-wise pest population/ disease severity. Various types of models developed were as follows.

3.2.1 Regression Models

The form of the model was

$$Y = f(X) + e$$

where Y is the pest population of the current week and f(X)'s are functions of X, X being weather variables with appropriate lags.

This model was tried for forewarning aphid in potato in various weeks. Different types of functions were tried. The appropriate functions found were cos, log and exponential. As an example, model for second week of January for aphid in potato (Pantnagar) was

$$Y = 80.25 + 35.78 \cos(6.81 X_{22} + 8.03) + 40.25 \cos(2.70 X_{12} - 14.82)$$

where X_{i2} (i =1, 2) are maximum temperature, minimum temperature lagged by 2 weeks i.e 1st week of December.

(Trivedi *et al.* 1998-99)

The observed and predicted values are given in Fig. 1.

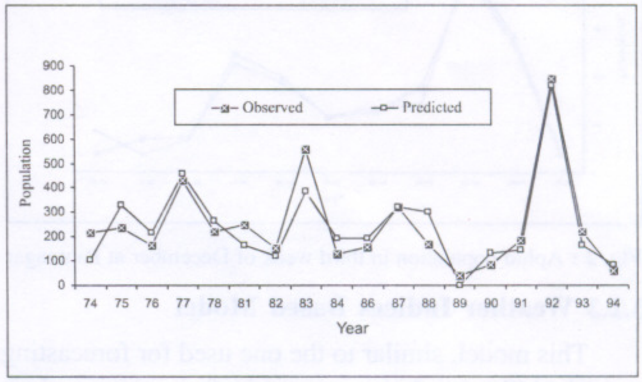

Fig. 1. Aphid population in third week of December at Pantnagar

3.2.2 Complex Polynomial through GMDH Technique

The form of the model was

$$Y = a + \sum_{i=1}^{m} b_i X_i + \sum_{i=1}^{m} \sum_{j=1}^{m} c_{ij} X_i X_j + \sum_{i=1}^{m} \sum_{j=1}^{m} \sum_{k=1}^{m} d_{ijk} X_i X_j X_k + \ldots$$

where Y is the pest population of the current week and X's are weather variables with appropriate lags.

For aphid in potato, this technique was also attempted. For example, the model for third week of December (Pantnagar) was

$$Y = 82.86 - 0.72\, G_1 - 0.35 G_2 + 0.004\, G_1^2 - 0.002\, G_2^2 + 0.007\, G_1 G_2 \quad (R^2 = 0.95)$$

where

$$G_1 = 496 + 1123.30\, X_{21} - 1172.12\, X_{22} - 85.59\, X_{21}^2 + 46.25 X_{22}^2 + 40.27\, X_{21} X_{22}$$

$$G_2 = -6359 + 477.80\, X_{11} + 42.93\, X_{32} - 12.65\, X_{11}^2 - 1.32 X_{32}^2 + 2.87\, X_{11} X_{32}$$

X_{ij} is i-th weather variable (i = 1, 2, 3 corresponding to maximum temperature, minimum temperature and relative humidity) in j-th lag week. (Trivedi *et al.* 1998-99)

Observed and predicted values from this model are given in Fig. 2.

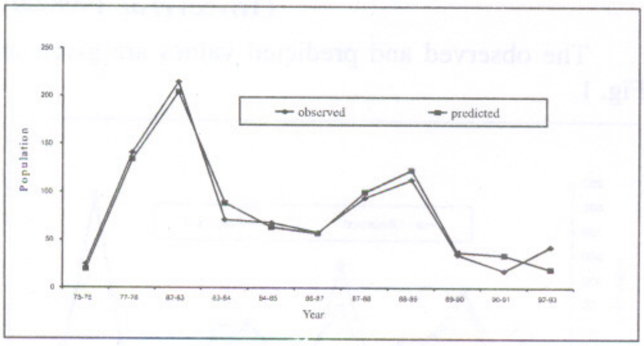

Fig. 2 : Aphid population in third week of December at Pantnagar

3.2.3 Weather Indices Based Model

This model, similar to the one used for forecasting crop yield (Section 2.1), was used for forecasting various aspects viz. maximum pest population/disease severity, crop age at time of first appearance, crop age at maximum pest population/disease severity and weekly pest population/disease severity for important pests and diseases of rice, mustard, pigeon pea, sugarcane, groundnut, cotton at various locations. The reliable forewarnings through this approach are possible at least one week in advance (Agrawal *et al.* 2004)

For example, in mustard, models were developed utilising weekly data starting from standard week of sowing up to 50th standard meteorological week i.e. second week of December for several years. The weather variables considered were maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity and bright sunshine hours- [X_1 to X_5] except for Morena and Bharatpur where data on bright sunshine hours was not available and therefore the models were based on only first four variables. For Kanpur, the variables considered were maximum temperature, minimum temperature, mean relative humidity, wind speed and evaporation-[X_1 to X_5]. The models for forecasting different aspects along with coefficient of determination (R^2) are presented in Table 3.

Models have been validated using data on subsequent years not included in developing the models. In most of the cases, there was good agreement between forecasts and observed values. Results of validation are given in Fig. 3 to 5.

Table 3. Models for forecasting different aspects of aphid (mustard)

Aspect	Centre	Model	R^2
Crop-age at first appearance	Behrampur	$Y = -32.75 + 0.009\, Z_{121} - 0.73\, Z_{20}$	0.99
	Pantnagar	$Y = 431.04 + 2.68\, Z_{31}$	0.56
	Hisar	$Y = 56.72 + 0.029\, Z_{241} + 2.74\, Z_{11}$	0.60
	Ludhiana	$Y = 198.12 + 0.14\, Z_{351} + 0.08\, Z_{451} - 0.011\, Z_{130}$	0.92
	Morena & Bharatpur	$Y = -112.91 + 0.02\, Z_{131} + 4.98\, Z_{11}$	0.71
	Kanpur	$Y = 7.96 + 0.42\, Z_{241}$	0.86
Crop-age at maximum population	Behrampur	$Y = 52.48 + 0.02\, Z_{121} + 1.58\, Z_{51}$	0.84
	Pantnagar	$Y = 53.75 + 0.02\, Z_{120}$	0.56
	Hisar	$Y = 102.19 + 0.30\, Z_{121} + 1.20\, Z_{50}$	0.85
	Ludhiana	$Y = -133.56 + 0.09\, Z_{241}$	0.67
	Morena & Bharatpur	$Y = 77.1 + 0.03\, Z_{121}$	0.63
	Kanpur	$Y = 74.07 + 0.04\, Z_{231}$	0.92
Maximum population	Behrampur	$Y = 327.34 - 0.039\, Z_{230} + 0.06\, Z_{141}$	0.99
	Pantnagar	$Y = 168.81 + 3.40\, Z_{241} + 101.22\, Z_{21}$	0.82
	Hisar	$Y = 88.47 + 5.03\, Z_{121} - 0.33\, Z_{450}$	0.98
	Ludhiana	$Y = -6114.29 + 9.46\, Z_{30} + 3.55\, Z_{451} + 113.07\, Z_{11} + 2.56\, Z_{131}$	0.95
	Morena & Bharatpur	$Y = 690.77 + 79.29\, Z_{21} - 0.019\, Z_{340}$	0.65
	Kanpur	$Y = 7531.96 + 882.83\, Z_{41} - 0.65\, Z_{130}$	0.75

Note : Morena and Bharatpur were taken together because these fall under same agro climatic zone.

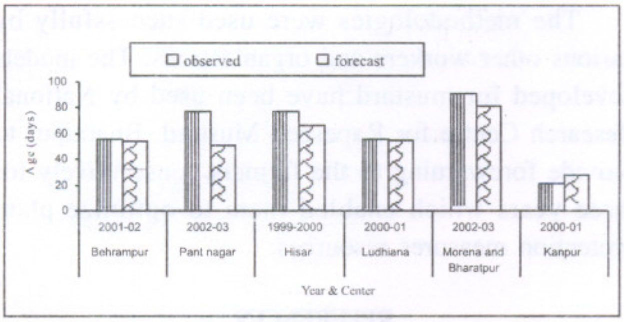

Fig. 3. Crop age at first appearance of aphid

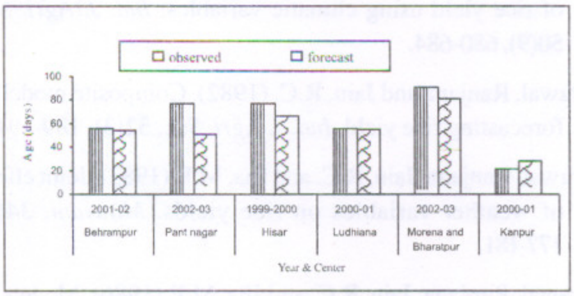

Fig. 4. Crop age at maximum population

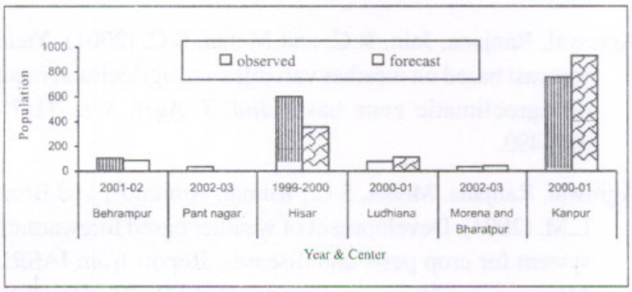

Fig 5. Maximum aphid population

The above models have been used to provide forewarning to the concerned farmers by National Research Centre for Rapeseed Mustard, Bharatpur consecutively for three years which enabled them to optimize plant protection measures.

3.2.4 Model by Deviation Method

Sometimes data are available only for few years (5-7 years) which are inadequate for development of separate week-wise models. In such cases, deviation method can be used. The pest population/disease severity at a given point of crop stage may be assumed to be due to two reasons - natural cycle of the pest/disease and weather. To identify the natural cycle, data at different intervals is averaged over years and a suitable model is fitted. Then a model is fitted using deviations from natural cycle as dependent and weather as independent variables.

Illustration. The above technique was applied for development of forecast model for weekly fruitfly population in mango at Rehman Khera Farm, Central Institute for Subtropical Horticulture, Lucknow. The forewarning model was developed on the basis of 6 years data (Mehta *et al.* 2001).

The model for natural pattern was

$$Y_t = \frac{33.64 - 1.79\,t}{1 - 0.16\,t + 0.0067\,t^2}$$

t = Week number, Y_t = Fruitfly population at week t.

The observed and predicted values are given in Fig. 6.

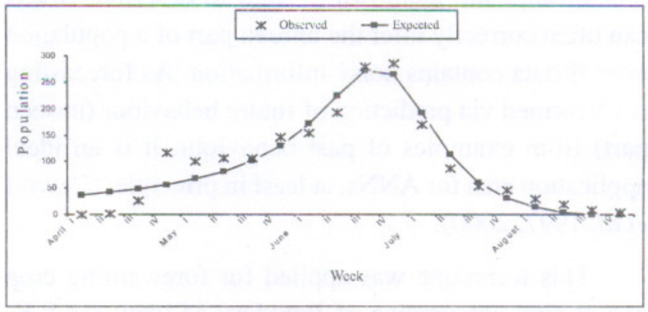

Fig. 6. Natural pattern of fruitfly

The final forecast model was

$$\begin{aligned} Y = & -125.766 + 0.665\,(Y_2) + 0.115\,(1/X_{22}^2) \\ & + 10.658\,(X_{12}^2) + 0.0013\,(Y_3^2) + 31.788\,(1/Y_3) \\ & - 21.317\,(X_{12}) - 2.149\,(1/X_{33}^2) - 1.746\,(1/X_{34}^2) \end{aligned}$$

Y = Deviation of fruitfly population from natural cycle

Y_i = Fruitfly population in i-th lag week

X_{ij} = Deviation from average of i-th weather variable (i = 1, 2, 3 corresponds to maximum temperature, minimum temperature and relative humidity) in j-th lag week

Using this model, forewarning can be issued one week in advance. Forewarnings for subsequent year are given in Fig. 7.

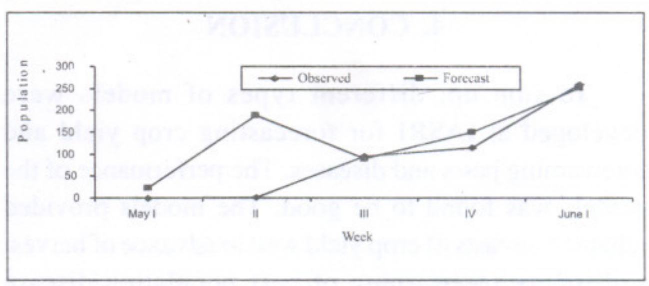

Fig. 7. Forecast of fruitfly population

It can be seen from the figure that all the forecasts (except May II week) are in good agreement with the observed populations.

3.2.5 Model using Artificial Neural Network Technique (ANN)

ANN provides an efficient alternative tool for forecasting purposes. ANNs are data driven self-adaptive methods in that there are few apriori assumptions about the models for problems under study. These learning from examples, capture subtle functional relationships among the data even if the underlying relationships are unknown or hard to describe. ANNs can often correctly infer the unseen part of a population even if data contains noisy information. As forecasting is performed via prediction of future behaviour (unseen part) from examples of past behaviour, it is an ideal application area for ANNs, at least in principle. (Dewolf *et al.* 1997, 2000).

This technique was applied for forewarning crop age at first appearance of Powdery Mildew for S.K. Nagar using data for four years on disease severity with different dates of sowing. The model was validated from the 5th year's data (Fig. 8). The technique worked very well for forewarning. (Agrawal *et al.* 2004).

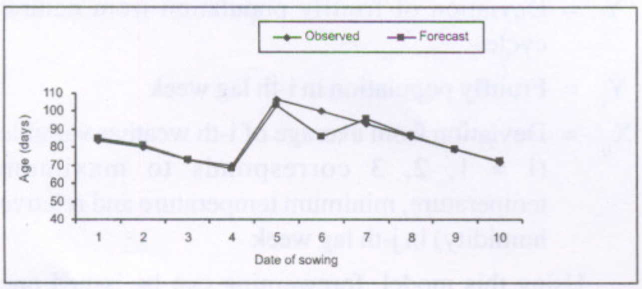

Fig. 8. Crop age at first appearance of Powdery Mildew (Mustard)

4. CONCLUSION

To sum up, different types of models were developed at IASRI for forecasting crop yield and forewarning pests and diseases. The performance of the models was found to be good. The models provided reliable forecasts of crop yield well in advance of harvest and timely forewarning of pest population/disease severity could be given.

The methodologies were used successfully by various other workers and organizations. The models developed for mustard have been used by National Research Centre for Rapeseed Mustard, Bharatpur to provide forewarning to the farmers consecutively for three years which enabled them to optimize plant protection measures resources.

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