Pre-harvest Crop Production Forecast Methodologies: IASRI Studies

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1. Introduction

Reliable forecasts of crop production before the harvest constitute a problem of topical interest. Such forecasts are needed by the Government, agro-based industries, traders and agriculturists alike. The Government needs these for use as a basis for its policy decisions in regard to procurement, distribution, buffer-stocking, import-export, price fixation and marketing of agricultural commodities while agro-based industries, traders and the agriculturists need forecasts for planning their operations properly. To meet such needs, crop forecasts under the prevalent system in India are being issued for principal crops at four points of time during a year by the Directorate of Economics and Statistics, Ministry of Agriculture (DESMOA), New Delhi. The first official forecast is issued in the middle of September, second is made in the month of January, third is prepared towards the end of March / beginning of April and fourth in the month of June. These forecasts are, however, of a subjective nature since these are based on eye-estimates and personal judgement of agricultural officials and the final crop production estimates, though based on objective crop-cutting experiments, are of limited utility as these become available quite later after the harvest.

In view of this, there is a need for an objective methodology for pre-harvest crop forecasting. This involves building up suitable forecast model(s) which has certain merits over the traditional forecasting method. These merits include the objectivity of the forecast and its ability to provide a measure of reliability which a traditional forecast method can not provide. This, as such, calls for the necessity of objective methods for pre-harvest forecast of crop yields. In this article, various studies undertaken at Indian Agricultural Statistics Research Institute (IASRI), New Delhi on crop forecasting have been presented.

2. Forecasting Studies at IASRI

As crop acreage and yield rates constitute the two components of crop production of which the former is available before harvest and the latter only after harvest, the work on forecasting at the Institute was restricted to developing yield forecast models. The main factors affecting crop yield are inputs and weather experienced by the crops during growth period. Use of data on these factors forms one approach for forecasting crop yields. The other approach uses plant vigour measured either through plant characters or through remotely sensed data. The second approach is based on the fact that various factors affect crop growth through plant processes. These effects are manifested through crop stand, number of tillers, root length, leaf area, number of ear heads etc., which ultimately determine crop yield. A number of techniques based on different types of data have been developed at the Institute for various crops. These are discussed in the following sections.

2.1 Weather based models

Crop yield is affected by technological change and weather variability. It can be assumed that the technological factors will increase yield smoothly through time and, therefore, years or some other parameter of time can be used to study the overall effect of technology on yield. The weather variability both within and between seasons is another and the only uncontrollable source of variability in yields. 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 and studying relationships of weather variables with crop yield in these 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.

Models using composite weather indices

Fisher (1924) and Hendricks & 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 divided the whole crop season into 5/7 days intervals. He assumed that the effect of change in weather variable in successive periods 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 weather variable in successive periods are composed of the terms of polynomial functions of time. Substituting these in usual regression model,

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

(here Y denoted yield and X_w weather variable in w^{th} period w = 1,2,....,n and e error term) 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 denoted parameters to be determined, ρ_i (i =1,…, k) distribution constants of X_w. 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 modified Fisher's technique. They assumed that a second degree polynomial in period number would be sufficiently flexible to express the effects in successive periods. Under this assumption, the model suggested by Hendricks and Scholl was

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

where A_0, a_0, a_1 & a_2 represented 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 IASRI, the model suggested by Hendricks and Scholl has been modified by expressing effect of changes in weather variables on yield in the w^{th} period as second degree polynomial in respective correlation coefficients between yield and weather variables [Agrawal *et al.* (1980), Agrawal and Jain (1982), Agrawal *et al*.(1983), Jain *et al.* (1980)]. This is expected to explain the relationship in a better way as it gives appropriate weightage to weather in different periods. 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 w^{th} period 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, (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.

$$Y = A_0 + a_0 Z_0 + a_1 Z_1 + cT + e \quad \text{where} \quad Z_j = \sum_{w=1}^{n} r_w^j X_w \quad ; \quad j = 0, 1$$

here r_w denoted correlation coefficient of weather variable in w^{th} period with yield (adjusted for trend effect, if present). 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

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

$r_{iw}/r_{ii'w}$ denoted correlation coefficient of yield (adjusted for trend effect, if present) with i^{th} weather variable/ product of i^{th} and $i`^{th}$ weather variables in w^{th} period, m period of forecast and p 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 weather variable over different periods, weights being correlation coefficients of weather variable in respective periods with yield (adjusted for trend effect, if present). Similarly, for interaction of weather variables, indices were generated using period-wise 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 Kolhapur 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 then 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 are 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. 2½ 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 below:

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 Application

Centre, Ahmedabad to obtain forecast for wheat yield at national level. The forecast thus obtained was with only 3% deviation from observed yield.

Model using discriminant function analysis

At district level, model based on time series data of weather variables was also developed using discriminant function analysis. The long series data of 25-30 years were 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 was carried out for rice in Raipur district. The performance of quadratic discriminant function was found to be better than linear discriminant function. This may 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 observed yield, about two months before harvest [Rai and Chandrahas (2000)].

In another study by Aditya (2008), use of discriminant function analysis has been studied for wheat crop in Kanpur district of Uttar Pradesh. Discriminant scores derived through different procedures were used as regressors in forecast models. The recommended model involved working out discriminant scores using weather data of first week, then obtaining discriminant scores using weather data of second week alongwith discriminant scores based on first week's weather variables and so on. Finally, two discriminant scores obtained using weather data of the last week and discriminant scores based on data upto previous week were used as regressors in the model alongwith the time trend. This model provided forecast of yield about one and a half months before harvest with deviation from the observed one around 5%.

Models using water balance technique

Using water balance technique, models have been developed for rainfed crops, rice (Raipur), sorghum (Delhi & Parbhani) and maize (Delhi). In this approach, water deficit/surplus has been 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 have been used as regressors alongwith 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

= $k_i \times evap_i$ (k_i crop coefficient and $evap_i$ pan evaporation in the i^{th} week)

Stress due to deficit, $St_i = 1 - AE_i / WR_i$, where AE_i 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)].

2.2 Plant characters based models

Effects of various causal factors (weather, inputs, etc.) are manifested through crop stand, number of tillers, leaf area, number of earheads, etc. which ultimately determine crop yield. As such, plant characters can be taken as the integrated effects of all the causal factors and may serve as good scientific indicators of plant condition. Considerable work has been done at the Institute for developing crop yield forecast models based on plant characters for paddy (Sambalpur, West Godavari, Delhi & Ludhiana), jute (24 Parganas & Purnea), wheat (Ludhiana, Delhi & Aligarh), jowar (Sangli), cotton (Baroda, Jalgaon & Aligarh), tobacco (Prakasam), sugarcane (Meerut & Kolhapur), apple (Shimla) and groundnut (Rajkot). Two types of approaches for modeling have been attempted - Between year model and Within year model.

2.2.1 Between year models

These models are developed taking previous year(s) data. Objective yield forecasts are obtained by substituting the current year plant data into a model developed from the previous year(s). An assumption is made that the present year is a part of the composite population of these (previous) years. The data utilized was on plant characters collected at different periodic intervals from farmers' fields using stratified multistage sampling design for 3-4 years taking Village Level Workers' circles/Community Development Blocks/Taluks in the selected district as strata. The samples were selected by selecting two villages as first stage units from each stratum, 2-4 fields from each selected village as second stage units and two plots per field as third stage units. In all, around 200-250 fields from a district have been selected for study in each crop. In case of apple crop, orchards and trees formed the second and third stage units respectively. The sampling units at each stage were selected by simple random sampling without replacement and were kept fixed for the entire crop season. Various models studied under this approach are as follows :

Linear regression model

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + ... + e$$

where Y represented crop yield, X_i's plant characters and β_0 & β_i 's regression coefficients. These models utilized data at one point of time only during the crop growth [Sardana *et al.* (1972), Singh *et al*. (1976), Jha *et al*. (1981), Singh and Bapat (1988), Rai, *et al.* (1998)]. In these models, the regressand Y and the regressors X_i's were used in the original scale and in some models, these were transformed to log, square root and reciprocal scales. As all the models were found roughly at par, for simplicity and ease in interpretation, the models using variables in original scale were recommended. This approach provided forecasts atleast one month before harvest for various crops at different locations. For cotton crop, first picking yield was also used alongwith plant characters in the model.

Model based on growth indices

The models using data at one point of time do not provide the idea of growth pattern of plant characters. Therefore, models using growth indices were attempted to improve upon usual linear regression models. In these models regressors were growth indices based on plant characters observed on two or more points of time during the crop growth which were obtained as weighted accumulations of observations on plant characters in different periods, weights being respective correlation coefficients between yield and plant characters. The form of the model was

$$Y = \beta_0 + \Sigma\, \beta_i G_i + e$$

where $G_i = \sum_{w=n_1}^{n_2} r_{iw} X_{iw}$ represented the index of the i^{th} character, w period identification, n_1 & n_2 the initial & final periods considered in developing the index of the character, r_{iw} simple/partial correlation coefficient between yield and i^{th} character in w^{th} period, X_{iw} the value of the i^{th} character in w^{th} period.

This model was attempted for hybrid jowar in Sangli district and was found better than conventional linear regression model [Jain *et al*. (1985)] .

Principal component regression

Forecast models were attempted using principal components of biometrical characters alongwith crop inputs as regressors. [Jain *et al.* (1984), Chandrahas *et al.* (1989)]. Principal components were obtained using data on biometrical characters at one or more points of time.

Probability model based on markov chain

In multiple regression approach least squares technique is used for estimating the parameters of the model. The optimality properties of these estimates are described in an ideal setting which is not often realised in practice. It has been observed that regression based on different subsets of data produces very different results, raising questions of model stability. To overcome some of the drawbacks of regression model, Markov Chain theory has been used for developing probability model for forecasting crop yield. This method, being completely model free, does not require any assumption about independent/dependent variables. Markov Chain method has the advantage of providing non parametric interval estimates and is robust against outliers/extreme values.

In this method, growth process of the crop is divided into phenological stages. A markov chain model is constructed by defining a set of states, which describe the average condition of a group of plants at specified time within the phenological stages. Individual states are defined on the basis of available qualitative and quantitative information to describe the plant condition. Transition matrices are worked out which give the transition probabilities of a plant (or a group of plants) moving from any possible state of any stage in the growth process to any state of next stage in the model. Predicted yield distributions are obtained by using transition matrices which are used to provide the yield forecast. This method was applied to forecast yield of sugarcane [Jain and Agrawal (1992(a)), Agrawal and Jain (1996)]. Models using higher order markov chain using data on plant characters as such / principal components/ growth indices of plant characters were also attempted [Jain and Ramasubramanian (1998), Ramasubramanian and Jain (1999), Ramasubramanian *et al.* (2004)].

2.2.2 Within year models

The between year models while performing satisfactorily in typical years may falter in atypical years. A model which uses data from the current growing season only may be beneficial in improving forecasts during a year with atypical growing conditions. Such approach will also be useful for forecasting crop yield in areas where past data are not available. These models had been developed to provide forecasts of pertinent components of crop yield relying entirely on growth data collected from plant observations during the current growing season. This approach has been attempted for rice and wheat using data collected from IARI Research farm, New Delhi.

Logistic model was used to model growth pattern of dry matter accumulation and head / panicle weight. Partial crop season data were utilised to fit the curve and the value of variables under study at harvest was predicted through this curve which in turn was used to forecast yield. As over-estimation was observed when the models were fitted using partial crop season data based on the data points falling on the lower side of the curve where growth has steep rise, the usual logistic model was modified so as to capture the value of variables under study at maturity from partial crop season data. The proposed modified logistic model was

$$Y_t = \frac{\alpha^{\sqrt{\frac{t_m}{t_f}}}}{\left(1+\beta\rho^t\right)} + e_t$$

where Y_t represented dependent growth variable, t independent time variable, t_m time of maturity and t_f time of forecast, a > 0, $\beta > 0$, 0 < r < 1.

The modified growth model worked well to adjust for over-estimation. By this approach, the forecasts of total dry matter and head / panicle weight at maturity were obtained about one month before harvest and 15 days before harvest respectively. The forecasts were found close to the observed ones [Jain et al. 1992(b)].

2.3 Use of farmers' appraisal in the model

Farmers are the best judge of the likely production in the field as the farmers engaged in the cultivation of the crop have their own inbuilt concept in their mind which takes into account the totality of the effects of input variables, climatic effects, a view of biometrical characters and also the soil characteristics to arrive at the expected yield. Farmers' appraisal, therefore, could serve as a good input for forecasting the yield and replace some of the characters requiring expertise or use of sophisticated instruments for their measurements and thus reducing the cost on data collection. A study has been carried out to study the feasibility of using farmers' appraisal in the forecast model for sugarcane [Agrawal and Jain (1996)]. The results revealed that a reliable forecast could be obtained using plant population and farmers' appraisal. Farmers' appraisal in this model has replaced plant height used in the model based on plant characters only.

Another methodology based on farmers' appraisal data has been developed using Bayesian approach. This approach for forecasting is basically based on the judgement / opinions / views of the target group in which the information is obtained directly about the concerned characters to arrive at a forecast. Chandrahas and Rai (2001) developed methodology for obtaining wheat yield forecast in Muzaffarnagar district using farmers' appraisal data through Bayesian approach. Expert opinion data were collected in a number of rounds by interviewing the selected farmers regarding their assessment about the likely crop production and chance of occurrences in various yield classes. From these responses average prior probabilities were computed. Actual harvest yield and farmers' appraisal data on yield for previous year(s) were taken into account to obtain posterior probabilities which were then used for obtaining Bayesian forecast of crop yield for current year. Forecast could be obtained about two months before harvest. The significant advantage of the Bayesian approach is that it provides forecasts representing the composite thinking of a number of farmers actually engaged in cultivation of the crop. This approach provides quick and less expensive forecasts and the accuracy is expected to be more than purely eye-estimate based forecasts.

2.4 Integrated model / composite forecast

The crop yield depends on many types of variables viz. weather factors, performance of plants during crop growth stages, agricultural inputs etc., therefore, it will be better if various aspects are considered in the forecast model. In this reference, a model has been tried using data on plant characters alongwith agricultural inputs for jowar (Jain *et al.* 1985). The results revealed that inclusion of date of sowing and fertilizer in the model increased the coefficient of determination by 8%. For apple and groundnut crops, integrated yield forecast models were attempted using data on biometrical characters, crop inputs and weather variables [Chandrahas and Narain (1992), Singh *et al.* (1991)].

Sometimes it is not possible to include all the variables in a single model. Therefore, a study has been carried out to obtain composite forecast as a suitable combination of forecasts obtained from different models. Various strategies for combining forecasts have been suggested under different situations [Mehta *et al.* (2000)].

2.5 Some aspects on sampling and error of forecast

Use of successive sampling

The forecast of crop yield based on biometrical characters involves the use of at least two years' data. The data of first year are used to set up the forecast model and the second year data on regressors to forecast the mean yield. Thus, the yield forecast estimator is a function of observations recorded in the two successive years. Accordingly, an attempt was made to provide a minimum variance linear unbiased estimator of yield forecast employing the theory of successive sampling. The study on optimum allocation of sample showed that independent sampling in the forecast year leads to more precise forecast [Chandrahas (1984)].

Error of forecast

Usually sampling design is ignored while fitting the models. The effect of sampling for regressors on the variance of forecast error was studied [Chandrahas (1984)]. The expression for error of forecast was derived by considering sampling and model components simultaneously [Jain *et al*. (1985)].

Effect of measurement errors on forecast

In fitting the models the regressors are normally assumed to be free from measurement errors which in practice may not be true. When the variables are subject to measurement errors, then as discussed by Cochran (1970), coefficient of determination R^2 gets reduced to $R^2.g_y.g_w$ where g_y is the coefficient of reliability of dependent variable and g_w is the weighted mean of the coefficients of reliabilities of regressors. Chandrahas and Rai (1998) worked on this aspect for developing forecast models for sugarcane crop. This study showed that coefficient of determination increases when the measurement errors were taken into consideration while analyzing the observed data. Use of replicated measurements for a number of units has been suggested to enable an estimation of the extent of measurement errors involved in the data.

Application of two-phase sampling

Models based on plant characters require periodical data collection from farmers' fields. Therefore, some characters involving high cost of data collection or use of sophisticated instruments, though important, may not find place in the models or else the sample size will be required to be reduced drastically with a view to keep cost on data collection within a reasonable limit. Goyal (2003) suggested the use of two-phase sampling wherein data on less costlier characters are collected from a larger sample and data on characters involving high cost or labour are collected from a sub-sample. The appropriate methodology for developing forecast model based on entire data (i.e. data on some characters on smaller sample and some characters on whole sample) has been suggested. The approach has been successfully demonstrated by forecasting sugarcane yield in Meerut district.

3. Conclusion

Models for forecasting yield of various crops at various locations have been developed at IASRI using various types of data / approaches. The weather (indices) based models have been studied in detail for different crops at various locations. The developed methodology has been demonstrated at district, agro-climatic zone as well as state level. The methodology has been successfully used by various research workers.

The approaches for which data collection from farmers' fields is required, can be integrated with crop cutting surveys where sample plots may be selected in advance using sampling design adopted under these surveys. The data required for forecasting purposes can be collected at required points of time from these plots and used for providing forecasts before harvest. The methodologies developed at IASRI can be more widely used throughout the country after pilot testing at other locations.

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