CROP YIELD ESTIMATION AND FORECASTING USING REMOTE SENSING

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1. Introduction

Agriculture is the backbone of Indian economy, contributing about 40 percent towards the Gross National Product (GNP) and providing livelihood to about 70 percent of the population. So for a primarily agriculture based country like India, reliable, accurate and timely information on types of crops grown and their acreages, crop yield and crop growth conditions are of vital importance. India is one of the few countries which has a well-established system of collection of agricultural statistics and detailed statistics of land utilization are continuously available since 1884. The agricultural crop production of principal agricultural crops in the country is usually estimated as a product of area under the crop and the average yield per unit area of the crop. The estimates of the crop acreage at a district level are obtained through complete enumeration whereas the average yield is obtained through general crop estimation surveys (GCES) based on crop cutting experiments conducted on a number of randomly selected fields in a sample of villages in the district.

The traditional approach of crop estimation in India involves a complete enumeration (except a few states where sample surveys are employed) for estimating crop acreages and sample surveys based on crop cutting experiments for estimating crop yield. The crop production estimates are obtained by taking product of crop acreage and the corresponding crop yield. The yield surveys are fairly extensive with plot yield data collected under a complex sampling design that is based on a stratified multistage random sampling design. In each district, tehsils/blocks form the strata, the villages in a block form the primary sampling units, the fields under the crop form second stage unit and at the third stage of sampling a plot of specified dimensions within a field is selected for harvesting to determine the crop yield. The sample units are randomly selected at each stage of sampling. For a detailed description of the methodology of data collection in crop surveys one may refer to Sukhatme and Panse (1951).

These crop surveys are planned with a specific population (district) in view. However in view of growing needs of micro level planning and especially the demand of crop insurance, the need for reliable small area crop statistics for sub populations (like Tehsil or Block) is increasing. But planning of surveys for Tehsil level estimates will require much larger number of crop cutting experiments and the costs involved will be quite prohibitive. The advances in remote sensing technology applications and also the advances in computing facilities have provided some convenient techniques of small area estimation which borrow strength from related or similar larger area through explicit and implicit models that connect the small area via supplementary data. Hence estimates at Tehsil level can be attempted through the crop surveys earlier planned for district level estimators.
The crop forecasts/advanced estimates of crops are presently developed by the Ministry of Agriculture. The advance estimates of kharif crops are first prepared in July/August tentatively when behavior of South West monsoon is clear and reports of coverage of area under crops from the states are available. The advance estimates are reviewed during December/January when estimates of area under kharif crop become available under the Timely Reporting Scheme (TRS) and results of the crop cutting experiments portion from the NSSO (normally 10%) become available. The advance estimates of rabi season are also prepared at this stage. The advance estimates are again reviewed in the month of April based on information obtained from the states giving the final forecast for kharif.

With the advent of Remote Sensing Technology during 1970s, its great potential in the field of agriculture have opened new vistas of improving the agricultural statistics system all over the world. Space borne remotely sensed spectral satellite data has been widely used in the field of agriculture for estimation of area under different major crops like wheat, paddy, groundnut and sugarcane. Studies have also been made to examine the relationship of crop growth parameters like leaf area index (LAI) representing crop vigour and the spectral data in the form of several vegetation indices developed from the spectral data of various bands. Remote sensing satellite data can also be used for improving the crop yield estimation through crop cutting experiments and also for developing models for crop yield using historical data, meteorological data along with the remotely sensed satellite data.

During 1990-93 a study was conducted at the Indian Agricultural Statistics Research Institute (IASRI), New Delhi to examine the usefulness of satellite spectral data for stratification of crop area based on vegetation indices for improving crop yield estimation based on yield data from crop cutting experiments under crop yield estimation surveys. The study pertained to wheat crop yield for district Sultanpur UP for 1985-86 and the satellite data was used from the USA satellite Land Sat-4. This study showed that the efficiency of crop yield estimation can be increased considerably by using the satellite data along with the survey data. The results of this study are given in Singh et. al.(1992). Another similar study was undertaken during 1996-98 for improved estimation of wheat crop yield in district Rohtak for 1995-1996 using the IRS 1B - LISS II satellite data. The results from this study presented in Singh et. al (1999). also showed that satellite data in the form of vegetation indices greatly improves the efficiency of crop yield estimator.

2. Crop Yield Estimation using Remote Sensing and Forecasting

Remote sensing technology has been proved as a useful application for natural resources evaluation and management. In the past, spectral data acquired via satellite have been extensively utilized for crop yield modeling in various parts of the world. The important assumption in use of remote sensing data for crop modeling is that the spectral data is strongly related with canopy parameters which are related to final yield at a critical stage of the crop growth. Several studies have established good correlation between vegetation indices and grain yield using single date data near heading/flowering like Colwell et al. 1997, Serafini 1985, Barnett and Thompson 1982, 83. In India a major project on “Crop Acreage and Production Estimation (CAPE) has been carried out under the Remote Sensing Applications Mission by Department of Agriculture and Cooperation and Department of Space to develop methodology for state level acreage and production estimation of important crops. Use of satellite spectral data in crop yield
estimation surveys was recently examined by Singh et al (1992). In the study satellite data at the time of maximum flowering/heading of the crop in the form of vegetation indices was used to stratify the crop area into vegetation vigour classes like high vegetation, average vegetation, poor vegetation etc. This was followed by developing certain post stratified estimator of crop yield based on yield data as obtained from crop cutting experiments. This study showed a substantial improvement in the efficiency of crop yield estimator as compared to the existing estimator. This suggested that with the use of satellite spectral data along with the survey data based on crop cutting experiment either the number of crop cutting experiments can be reduced resulting in considerable reduction in the cost for obtaining district level estimate with the same precision or small area estimates at a lower level compared to the district (like tehsils or blocks) can be obtained with the existing crop cutting experiments in a district.

2.1 Estimation Procedure Based on use of Crop Yield Survey Data Along with Satellite Spectral Data.

The factors like different soil types, agricultural inputs, adoption of improved technology, etc. affect the crop yield and hence cause a lot of variability in the yield even within a stratum. Since the spectral reflectance is a manifestation of all important factors affecting the crop, hence a stratification of crop area on the basis of crop vigour as reflected by the spectral data is expected to result in a greater efficiency of the crop yield estimation. Singh et.al. (1992), Singh and Goyal (1993) showed that the stratification based on NDVI at heading/flowering stage improved the efficiency of crop yield estimation considerably.

In the present study it is proposed to develop post stratified estimator of crop yield, for district Rohtak in Haryana and also to develop small area crop yield estimates at tehsil level using the crop yield survey data and the satellite spectral data. Crop yield data for 1995-96 obtained from general crop yield estimation surveys and the satellite spectral data of IRS-1B LISS-II dated Feb. 17, 1996 have been used in the study.

Initially District Boundary Mask was generated using the topographic maps of scale 1:250,000. False Colour Composite (FCC) using spectral data from band-2 (Green) band-3 (Red) and band-4 (Near infra red) was generated Figure 1 presents the FCC for district Rohtak. For identifying the villages selected for crop surveys on the FCC, topographic maps of scale 1:50,000 which contain information on identifiable features like roads, canals, water bodies etc. were used. Further, a Global Positioning System (GPS) was used to identify the crop plots. The GPS was taken to the plots and location of the plots in terms of longitudes and latitudes were recorded. These locations were then identified on the FCC’s. The coordinates of each plot in terms of scanline and column number were recorded to identify these plots on the Normalized Difference Vegetation Index (NDVI) and the Ratio Vegetation Index (RVI) imageries. NDVI is defined as the ratio of (IR-R) to (IR+R) and RVI is defined as ratio of IR to R where IR and R denote the radiance in infra red (band 4) and red (band 3) respectively. The concept of density slicing technique was used to divide the NDVI and RVI imageries into different identifiable classes which provided three classes named as (i) Non vegetation class, (ii) Average vegetation class and (iii) the High vegetation class. To obtain the strata weights for the two vegetation classes, the number of pixels falling into these classes were obtained and since the pixel size is fixed, hence the area of the classes were obtained which were used as strata weights. Assigning different colours to different class range values, the stratified imageries were developed.
2.2. Estimation of Crop Yield at District Level

Initially FCC using spectral data from band -2 (Green band) band-3 (Red band) and band-4 (Near infra red band) were generated. For identifying the villages selected for crop surveys on the FCC, topographic maps of scale 1:50,000, which contain information on identifiable features like roads, canals, water bodies etc., were used. Further, a Global Positioning System (GPS) was used to identify the crop plots on imageries. The GPS was taken to the plots and location of the plots in terms of longitudes and latitudes were recorded. These locations were then identified on the FCC’s. The coordinates of each plot in terms of scanline and column number were also recorded to identify these plots on the Normalized Difference Vegetation Index (NDVI) imageries. NDVI is defined as the ratio of (IR-R) to (IR+R) where IR and R denote the radiance in infra red (band 4) and red (band 3) respectively. The concept of density slicing technique was used to divide the NDVI imageries into three classes named as (I) Non vegetation class, (ii) Average vegetation class and (iii) the High vegetation class. To obtain the strata weights for the two vegetation classes, the number of pixels falling into these classes were obtained and since the pixel size is fixed, hence the area of the classes were obtained which were used as strata weights.

To obtain the post-stratified estimator, let us assume that n villages selected in the sample have been post-stratified into \( L \)’ strata such that \( n_k \) villages fall in the k-th post-stratum. Let \( y_{ijk} \) denote the yield for the j-th field in the i-th village of the k-th post stratum.

The sample mean for the k-th post stratum can be defined as

\[
\bar{y}_k = \frac{\sum_{i} \sum_{j} y_{ijk}}{m_k}
\]  

where \( m_k \) is total number of field experiments falling in the k-th post-strata.

Now the post stratified estimator of district average yield can be given by

\[
\bar{y} = \frac{\sum_{k} A_k \bar{y}_k}{\sum_{k} A_k} = \frac{L'}{\sum_{k} W_k} \bar{y}_k
\]  

Where \( A_k \) denotes the area under crop in the k-th post-stratum. \( W_k = \frac{A_k}{\sum A_k} \)

Ignoring the pre stratification and also ignoring the contribution to sampling error due to post stratification the Variance and the Estimator of variance of \( \bar{y} \) can be obtained easily given by

\[
V(\bar{y}) = \sum_{k} W_k^2 V(\bar{y}_k)
\]  

and

\[
\hat{V}(\bar{y}) = \sum_{k} W_k^2 \hat{V}(\bar{y}_k)
\]
The estimates of crop yield based on usual estimator (without using satellite data) and the post-stratified estimators based on NDVI and RVI are given in Table 1 below. From these results it is seen that the new estimators are significantly more efficient compared to the usual estimator of crop yield at district level.

2.3 Small Area Estimation of Crop Yield at Tehsil/Block Level

Issue of small area estimation has gained importance in view of growing needs of micro level planning. Most of the small area estimation techniques in the early stages were developed in the context of demographic studies. Purcell and Kish (1979) categorise these areas under the general heading of Symptomatic Accounting Techniques (SAT). Gonzalez (1973) described a small area estimation technique well known as synthetic estimator. In this method an unbiased estimate is obtained from a sample survey for a larger area and this estimate is used to derive estimates for sub areas having the same characteristics as the larger area.

Let the population (a district) consist of T small areas (Tehsil/Block). Further let the district area be divided into V post strata representing crop condition like very good crop, average crop, poor crop, no crop etc. based on the vegetation indices derived from the satellite spectral data. The crop within these post strata is generally homogeneous in respect of the character under study (the crop yield) and the boundaries of these post strata cut across the small areas. Hence it can be easily assumed that the units within a small area belonging to particular post strata will have the same characteristics as the units belonging to that particular post strata irrespective of the small area.

In order to develop crop yield estimates at tehsil level from general crop yield estimation surveys based on crop cutting experiments we propose two estimators namely (i) The Direct estimator and (ii) The Synthetic estimator. These estimators make use of available information on crop yield and also the information of crop acreage for all the post strata which overlap the tehsil. It has been seen earlier from the results that stratification based on NDVI provide more efficient estimate of crop yield for the district as a whole. Therefore, for small area estimator only NDVI has been used to develop post strata.

2.3.1 Direct Estimator

Let y and x denote the character under study, the crop yield and the auxiliary variable, the crop acreage respectively. Let $y_{tvi}$ denote the crop yield for the i-th plot in the t-th tehsil and v-th post-strata and let $n_{tv}$ denote the number of sample observations belonging to the t-th tehsil in the v-th post strata. If all $n_{tv}$’s are greater than zero then an unbiased post stratified estimator known as the Direct Estimator for crop yield may be obtained as

$$\bar{y}_{dt} = \sum_{v} W_{tv} \bar{y}_{tv} \tag{4.1}$$

where, $\bar{y}_{tv} = \frac{1}{n_{tv}} \sum_{i} y_{tvi}$ is the average yield for tv-th cell

$$W_{tv} = \frac{X_{tv} \cdot X_{oo}}{X_{to} \cdot X_{o0}}, \quad X_{tv} \text{ is the crop acreage for tv-th cell}$$
\( X_{to} = \sum_{v} X_{tv} \) is the crop acreage for t-th tehsil

\( X_{ov} = \sum_{t} X_{tv} \) is the crop area for the v-th post stratum, and

\( X_{oo} = \sum_{t} X_{to} = \sum_{v} X_{ov} = \sum_{t} \sum_{v} X_{tv} \), total crop acreage in the district.

The approximate estimate of variance of \( \tilde{y}_{dt} \) can be written as

\[
\hat{V}(\tilde{y}_{dt}) = \sum_{v} w_{nv}^2 \hat{V}(\tilde{y}_{iv})
\]

where

\[
\hat{V}(\tilde{y}_{iv}) = \frac{s_{nv}^2}{n_{nv}}
\]

\[
s_{nv}^2 = \frac{1}{n_{nv} - 1} \sum_{i} (y_{iv} - \bar{y}_{iv})^2
\]

### 2.3.2 Synthetic Estimator

The Direct Estimator is based on only the number of crop cutting experiments belonging to t-th tehsil in the post strata which is quite small and hence the estimator will not be very efficient.

To improve the efficiency of the Direct Estimator a Synthetic Estimator denoted by \( \bar{y}_{st} \) is proposed which make use of the information from the whole sample,

\[
\bar{y}_{st} = \sum_{v} w_{nv}' \bar{y}_{ov}, \quad \text{where} \quad w_{nv}' = \frac{X_{nv}}{X_{to}} \quad \text{and} \quad \bar{y}_{ov} \quad \text{is the average crop yield for the v-th post stratum}
\]

The estimator of variance of \( \bar{y}_{st} \) can be approximately written as

\[
\hat{V}(\bar{y}_{st}) = \sum_{v} w_{nv}^2 \hat{V}(\bar{y}_{ov})
\]

\[
= \sum_{v} w_{nv}^2 \sum_{i} \hat{V}(\bar{y}_{iv})
\]

Since, sample in each tehsil has been selected independently.

### 3. Crop Forecasting Using Remote Sensing

Forecasting of crop production is one of the most important aspect of agricultural statistics system. The main factors affecting crop yield are inputs and weather. Use of these factors forms one class of models for forecasting crop yields. The other approach uses plant vigour measured through plant characters. It is assumed that plant characters are integrated affects of all the factors affecting yield. Yet another approach is measurement of crop vigour through remotely sensed data. These approaches are being tried by various organizations.
Box and Jenkins (1976) used time series models for forecasting where the variation in yield during different years is explained using historical data through trend analysis and presented the well known technique of auto regressive integrated moving averages ARIMA. The approach using weather parameters is normally based on time series data. The major work in this regard has been attempted at IMD (Sarker, 1977, Sarwade, 1988). Their studies involve identification of significant weather parameters in different periods and utilizing these parameters in the regression model along with trend. At IASRI, studies have been carried out at district level using weekly weather parameters. Various composite weather variables were derived as weighted accumulations of weekly weather parameters/interactions up to the time of forecast and were used as regressors in the model along with trend. Principal components of weather variables were also tried for developing the models (Agarwal et al.1986; Jain et al. 1980). The problem associated with meteorological model is assumption of same weather prevailing in a larger area as observatories are sparsely located. These models also require long series of data, which are not available for most of the locations.

The other approach using plant characters collected at farmers’ fields has been attempted through pilot studies at IASRI, New Delhi. The data have been collected at different periodic intervals through suitable sampling design for 3 to 4 years. Mainly two types of models, between year and within year models have been used. Between year models are based on historic data and involve an assumption that present year is a part of the composite population of the previous years. These models utilize the plant characters at some suitable phenological stage of crop growth either as such or their suitable transformations through multiple regression technique (Sardana et al.1972; Jha et al. 1981, Singh et al. 1988). Models were also developed using plant characters data of two or more periods through growth indices/principal components (Jain et al. 1984, 1985). Agarwal, Jain and Jha (1986) studied models based on crop weather relationship for Rice.

In case of crop yield modeling using satellite data, several studies have been undertaken to establish relationship between spectral parameters through vegetation indices and the crop yield. Sridhar et. al.(1994) presented wheat production forecasting for a predominantly un-irrigated region in Madhya Pradesh. Singh and Ibrahim (1996) examined the use of multi date satellite spectral data for crop yield modeling using Markov Chain Model. Saha (1999) used satellite data and GIS for a developing several crop yield models.

A study on "Evaluation of crop cut method and farmers reports for estimating crop production"(Verma et al (1988)) was undertaken at Longacre Agricultural Development Centre UK. This study was carried out in 5 countries in Africa during 1987 with the objective of comparing crop estimates based on crop cut methods with estimates obtained by asking farmers directly to state their production. The results of the study showed that farmers eye estimates are remarkably close to actual production figures in all the countries and they also show considerably small variance compared to the estimates based on crop cutting experiments. After the publication of this report considerable interest is again focused on using farmers estimates which are much cheaper to obtain and easier to conduct.

Singh (2003) made an effort to use the farmers eye estimate more objectively as a auxiliary variable along with the spectral indices based on remote sensing satellite data.
to improve the efficiency of crop yield models for forecasting crop yield. Details of this study are given here.

3.1 Study Area and Extent of Data Used in the Study

The study was conducted for district Rohtak of Haryana State which is one of the major wheat growing areas having an acreage of more than 66 percent under wheat crop during Rabi season. In the present study the yield data for the Rabi season for the years 1995-96 and 1997-98 from general crop estimation surveys based on crop cutting experiments for wheat crop for district Rohtak, Haryana has been used. The satellite data in the study has been used for 1995-96 from IRS-1B, LISS-II of path 30 and Row 47 of 17th February, 1996. The total area of Rohtak district is covered in one sub scene B2 of 30-47. For 1997-98 IRS-1D data of sensor LISS-III of path 95 and row 51 for Feb. 4th, 1998 has been used. A topographic map is the best tool to supply ground truth information for visual interpretation and identification of various features on satellite imageries. From these maps locations of villages along with related features like continuous roads, canals, railway tracks etc. can be easily identified on FCC’s. Survey of India topographical maps of Rohtak district on 1:50,000 scale were used to identify the location of villages selected for the crop yield estimation surveys.

A Global Positioning System (GPS) was used to identify the locations of the plots selected for crop cutting experiment for wheat crop in terms of their latitudes/longitudes and also the locations of ground control points (GCP’s) which were later used to rectify the raw digital spectral data. Farmers yield appraisal data has been collected for the years 1995-96 and 1997-98 for wheat crop yield from the same farmers for only the fields which have been selected for crop cutting experiments in general crop estimation surveys.

3.2 Vegetation Indices

Spectral response characteristics of healthy vegetation, can easily be characterised in the different parts of the electromagnetic spectrum. To further enhance the discrimination between different spectral vegetation classes, computation of different vegetation indices using infrared and red band data in the electromagnetic spectrum, for describing the crop growth conditions, are commonly used. Two most commonly used vegetation indices are:

(i) The Normalized Difference Vegetation Index (NDVI) defined as

\[ NDVI = \frac{IR - R}{IR + R}, \]

and

(ii) The Ratio Vegetation Indices (RVI) defined as

\[ RVI = \frac{IR}{R} \]

Where IR and R refer to radiance in infrared (band-4) and red (band-3) bands of the satellite. These two indices have been used in the present study to generate the index images for post-stratification of the study area on the basis of vegetation vigour.

3.3 Spectral Yield Model
These are empirical models which directly relates the crop yield to the multi-spectral satellite data or derived parameters in the form of spectral vegetation indices (SVI). In this procedure SVI at the time of maximum vegetation growth stage of the crop is related to final crop yield through regression techniques and pre harvest crop yield is forecasted. In India district level yield models for major crops like wheat, paddy, sorghum etc. have been developed under crop acreage and production estimation (CAPE) project undertaken by National Remote Sensing Agency (NRSA), Hyderabad, Deptt. of Space. However these models could explain about 60% variation in yield and hence are not very efficient.

3.4 Integrated Yield Model using Spectral Data and Farmers Eye Estimate of Crop Yield

Most of the crop yield models developed so far could not be adopted in practice either because of delay in the availability of data on different variables to be used in the model or the high cost in collecting the data and in analyzing the results. For any operational yield model to be successful for adoption it is necessary that data should be available much before the harvest of the crop and it should be cost effective. Spectral data in the form of vegetation indices have proved to be very useful variable for explaining variability of the crop yield which can be easily available for use in yield forecasting models. Also the farmers eye estimate of yield is easily available and this information can be used as auxiliary variable along with the spectral vegetation indices to improve the efficiency of the crop yield models. An earlier such attempt on using eye appraisal of crop yield of a large number of sample fields as auxiliary information had been made by Panse, Rajgopalan and Pillai (1966).

In the present study, therefore suitable regression models using spectral vegetation indices in the form of NDVI and RVI and farmers eye estimate of yield as explanatory variables have been developed for improved crop yield forecasting models. Both these variables can be easily obtained at the time of maximum growth of crop.

3.5. Results of the Study Pertaining to Crop Forecasting

The usual linear regression based models have been developed with the crop yield (y) as the dependent variable and three independent variables, namely RVI (x₁), NDVI (x₂) and the farmer’s eye estimate of crop yield of the corresponding plot (x₃). The models have been developed using the data for the Rabi 1995-96. These models have been used to forecast the crop yield for Rabi 1997-98 using the independent variables for 1997-98. The results and predicted value of crop yield using different independent variables independently as well as together are given in table 3. From this table it is seen that R² value is 0.45 and 0.54 respectively when only RVI and NDVI alone are used in the model and it increases to 0.59 when both these variables are used. However the R² value is 0.86 when only farmers eye estimate is used as the explanatory variable and the R² value increases to around 0.90 when it is used along with RVI or along with NDVI or along with both RVI and NDVI together. The deviation of the predicted yield from the actual yield is very low. In almost all the cases it is less than 2%. The standard error of the predicted value is also small in all the cases and as expected it is minimum when all the three variables are used together but it is not much different in the case when only farmers eye estimate and NDVI is used.
The results suggest that a reliable and timely forecast may be obtained using NDVI from the satellite data along with the farmers eye estimate as the two explanatory variables. These both variables can be obtained at the time of maximum vigour of the crop and hence objective reliable forecast may be made about 6-8 weeks before actual harvest of the crop.
Table-1: Distribution of grey values and area of different strata based on RVI and NDVI for District Rohtak for Rabi 1995-96 and 1997-98.

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Stratum/Veg classes</th>
<th>Range ofgrey values</th>
<th>No.of villages selected</th>
<th>Area Sq.Km.</th>
<th>Range of grey values</th>
<th>No.of villages selected</th>
<th>Area Sq.Km.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NDVI</td>
<td>RVI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995-96</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>NonVegetation</td>
<td>0-167</td>
<td>-</td>
<td>934.986</td>
<td>0.67</td>
<td>-</td>
<td>851.412</td>
</tr>
<tr>
<td>3.</td>
<td>High vegetation</td>
<td>218-255</td>
<td>36</td>
<td>1240.109</td>
<td>188-255</td>
<td>33</td>
<td>1226.468</td>
</tr>
<tr>
<td>1997-98</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>NonVegetation</td>
<td>0-167</td>
<td>-</td>
<td>1525.38</td>
<td>0.78</td>
<td>-</td>
<td>1440.07</td>
</tr>
<tr>
<td>2.</td>
<td>Av.-vegetation</td>
<td>168-214</td>
<td>30</td>
<td>861.62</td>
<td>79-186</td>
<td>31</td>
<td>908.64</td>
</tr>
</tbody>
</table>
### Table-2: Wheat crop yield forecasting model using RVI ($x_1$), NDVI ($x_2$) and the farmers eye Estimate ($x_3$) as independent variables for district Rohtak for forecasting crop yield for Rabi 1997-98. (using the model based on data for Rabi 1995-96).

<table>
<thead>
<tr>
<th>Model</th>
<th>$R^2$</th>
<th>$a$</th>
<th>$b$</th>
<th>Predicted value (Q/hac.)</th>
<th>%S.E.</th>
<th>Percentage of Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y = a + b_1 x_1$</td>
<td>0.451596 (3.102028)</td>
<td>3.3445 (0.5724)</td>
<td>4.251948 (1.998869)</td>
<td>35.86 (4.8568)</td>
<td>13.5434</td>
<td>0.1653</td>
</tr>
<tr>
<td>$y = a + b_1 x_2$</td>
<td>0.543511 (2.830157)</td>
<td>-6.18267 (2.721178)</td>
<td>44.87417 (5.024239)</td>
<td>35.86 (4.7004)</td>
<td>13.1071</td>
<td>0.1652</td>
</tr>
<tr>
<td>$y = a + b_1 x_3$</td>
<td>0.867496 (1.124314)</td>
<td>2.036448 (1.52888)</td>
<td>0.216212 (0.021125)</td>
<td>34.85 (2.1200)</td>
<td>6.0828</td>
<td>3.0619</td>
</tr>
<tr>
<td>$y = a + b_1 x_1 + b_2 x_2$</td>
<td>0.59259 (2.03613)</td>
<td>-3.798801 (8.212242)</td>
<td>$b_1 = -2.53 (5.09)$</td>
<td>$b_2 = 55.99 (46.45)$</td>
<td>35.22 (5.2418)</td>
<td>14.8829</td>
</tr>
<tr>
<td>$y = a + b_1 x_1 + b_2 x_3$</td>
<td>0.90009 (1.00829)</td>
<td>0.785252 (1.479713)</td>
<td>$b_1 = 1.14 (0.51)$</td>
<td>$b_2 = 0.17 (0.02)$</td>
<td>34.86 (1.8352)</td>
<td>5.2647</td>
</tr>
<tr>
<td>$y = a + b_1 x_2 + b_2 x_3$</td>
<td>0.90345 (0.99122)</td>
<td>-1.049277 (1.865161)</td>
<td>$b_1 = 11.21 (1.67)$</td>
<td>$b_2 = 0.17 (0.025)$</td>
<td>34.86 (1.8046)</td>
<td>5.1771</td>
</tr>
<tr>
<td>$y = a + b_1 x_1 + b_2 x_2 + b_3 x_3$</td>
<td>0.90406 (1.02274)</td>
<td>-2.144346 (4.132285)</td>
<td>$b_1 = -0.77 (2.57)$</td>
<td>$b_2 = 18.25 (23.99)$</td>
<td>$b_3 = 0.17 (0.025)$</td>
<td>34.86 (1.7992)</td>
</tr>
</tbody>
</table>

Actual crop yield for Rabi 1997-98 =35.92 (Q/hac) (Figures in braces give the standard error)
References


Singh, Randhir (2003) “Use of satellite data and farmers eye estimate of yield for crop yield forecasting” submitted for publication to the JISAS.
