WHEAT PRODUCTION ESTIMATION USING REMOTE SENSING DATA: AN INDIAN EXPERIENCE

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ABSTRACT:

The present paper highlights the experience of development of satellite-based methodology, results and achievements of wheat production forecasting in Haryana state of India under the project since 1989-90. Haryana with a geographical area of 44,212 km2 is the major agricultural state of the country. At the beginning of the project the area estimates were provided at the state level and then at district-level. Subsequently, the work on production estimation was also started in the year 1990 at the district level.

Single date in-season digital satellite data coinciding with peak vegetative stage of wheat crop was analyzed for wheat acreage estimation using Maximum Likelihood (MXL) supervised classification. Ground truth is collected near synchronous to satellite pass from large contiguous and homogeneous sites of wheat grown under different physiographic conditions. To save the computer timings and to complete the estimates in the large areas of the state well in time, stratified random sample segment approach has been adopted for analysis. The segment size was initially kept at 10*10 km which was reduced to 7.5*7.5 km and finally to 5*5 km. The sampling fraction was also increased from 10 to 20 percent. However, complete enumeration approach was followed subsequently, that involved analysis of the satellite data for the complete district, as the computer speed and capacity increased and the size of the districts decreased with creation of new districts in the state. Yield of wheat was estimated using multiple regression models developed using satellite based spectral vegetation indices along with meteorological and historical yield data. Zonal Spectro-trend, Trend-agromet and Spectro-trend-agromet models for wheat production forecasting were developed for different regions of the state of which the last one gave the best results. The performance of wheat acreage and yield estimates was evaluated by computing Relative Deviations (RD%) with Department of Agriculture (DOA) estimates.

It was observed that the area and production estimates improved with decrease in the segment size and increase in the sample segment as the size of various district decreased gradually. During the last 15 years of estimation the spatial resolution of the satellite data has gradually improved from 80 meter of MSS to IRS-IA/ IB/ lC/ ID (LISS-I/ II) and finally 23.5m LISS-III of Resourcesat which is being currently used for this purpose. Besides the spatial resolution, the spectral and temporal resolution of the satellite data has also improved which drastically improved the crop discrimination. Both accuracy as well as precision of the estimates improved over the years, as reflected by the relative deviation and CV values respectively, for various districts. However, the northern districts having large contiguous areas of the crop showed better accuracy and precision as compared to southern districts having a mix of various crops. Presently remote sensing technology is able to provide district level acreage and production estimates with 95 % accuracy.

1 INTRODUCTION

The use of Remotely Sensed (RS) data is being investigated all over the world crop production forecasting. Crop production consists of two components, i) area under the crop, and ii) yield per unit area. Acreage estimation using RS data has been demonstrated in various parts of the world. Dadhwal and Parihar (1985) made first attempt in India towards the use of satellite digital data for wheat acreage estimation in Karnal district of Haryana State. A project on Crop Acreage and Production Estimation (CAPE) under the Remote Sensing Applications Mission (RSAM) with enlarged scope and objectives was formulated in 1986. A concentrated effort has been made under this programme to develop methodology applicable over large areas (Sahai and Dadhwal, 1990).

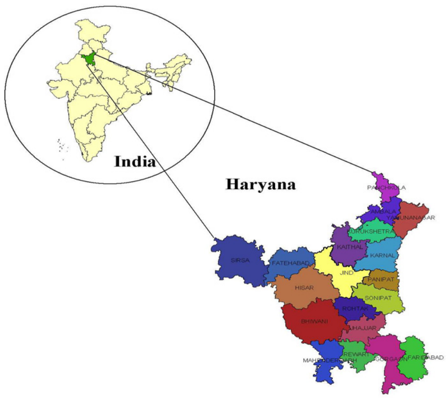
However, yield prediction is a subject of intensive research and is still at a developmental stage. Remote Sensing (RS) can provide information on important crop growth variables on a regional scale. Vegetation Indices (VIs) derived from RS data acquired at maximum vegetative growth stage are indicative of crop growth, vigour and potential grain yield. Numerous factors including weather parameters and agronomic practices, which vary from area to area affect crop yield in a given region. Over the past decade, a number of crop yield forecasting models using RS data have been developed (ldso et. al., 1980; Dubey et al., 1994; Datta et. al. 1995.; Kalubarme et. al., 1998 and Urmil Verma et. al. 2003).

The work on production forecasting using satellite data for major crops of Haryana state is being carried out under CAPE project for the last about 16 years. The present paper deliberates on the development of satellite-based methodology for wheat yield forecasting, improvements in accuracy and timeliness and experience gained in the field over the years using mostly the data from a series of Indian Remote Sensing (IRS) series of satellites.

2 STUDY AREA

All the districts of the state were covered for wheat estimation. Initially the state had 12 district which subsequently increased to 20 with the creation of 8 new districts in different years. Haryana state lying between latitude 270 39' 00'' to 300 55' 05'' N and longitude 740 27' 08'' to 770 36' 05'' E covers the total geographical area of 44212 sq. km. Wheat crop is grown in all the 20 districts of the state with varying density. The density of crop increases from northern to central districts. The districts of Kurukshetra, Kaithal, Karnal, Panipat, Jind, Rohtak, Sonipat and Jhajjar have the maximum density of the crop. The crop density again decreases in the south-western district which have sandy areas and limited irrigation facilities. Almost 99 percent of wheat crop in the state is grown under assured irrigation. The annual rainfall in the state range from 400 mm in the south-western part to 1400 mm in the northern Shiwalik hill areas. The crop is grown during the winter season known as Rabi season in the state. Sowing is generally done in the month of November and December and crop is harvest in the middle of April. Location of the study area is provided in figure 1.

LOCATION MAP



Important information about Haryana state is provided below:

	Area (sq km)	
Geog. Area	44212	
Net sown area	34580	(78.2%)
Double crop area	25770	(58.3%)
Gross crop area	60350	(136.5%)
Cropping intensity	175 %	
Wheat area	22670	(51.3%)
Forest area	1558	(3.5%)

(figures in parenthesis indicate % of total geographical area)

No. of Villages	6955
No. of Towns	84
No. of Districts	20

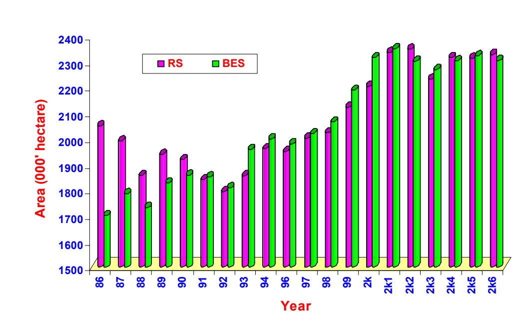
Population (2001 Census)

Total	21.15 million
Rural	71%
Urban	29%
Density	478 per sq km

3 DATA USED

Data from a variety of satellites were used depending upon the availability since the beginning of the project. Initially data only from American Landsat Satellite was available. Subsequently, with the launch of a series of Indian Remote Sensing Satellites (IRS), their data was opted for use due to easy availability and less cost. The spatial resolution of the satellite data continued to increase with the advancement in the sensors from new generation satellites. The list of satellites/ sensors whose data was used is provided in table 1 below.

Fig. 2. Wheat Area Estimates in Haryana



Satellite	Sensor	Spatial Resolution (m)
LANDSAT	MSS	80
LANDSAT	TM	32
IRS1A/1B	LISS-I	72
IRS1A/1B	LISS-II	36
IRS1C/1D	LISS-III	24
Resourcesat-P6	LISS-III	24

Table 1. List of satellites/ sensors and their spatial resolution

Single date satellite data acquired around the peak vegetative stage of wheat crop i.e. around third week of February was used for analysis. Satellite data date normalization was done by generating a profile curve of the crop to overcome the variation in the date of data acquired.

4 METHODOLOGY

4.1 Stratified Random Sampling / Complete Enumeration Approach

Initially looking into the limitations of digital computer processing speed and reducing the time of analysis stratified random sampling approach was used. The stratification was done by overlaying a 10*10 km grid over the previous year satellite data and visually categorizing each segment into A, B, C, D or Non-agricultural (NA) type based upon the spread of agriculture in each segment as under:

A > 75% B = 50-75% C =25-50% D = 5-25% NA < 5%

Subsequently, Digital Stratification based upon thresholding of Vegetation Index was attempted and found to be more accurate and easy to use. With the changes in the land use new stratification was done with fresh satellite data after every 3-5 years. Segment size which was 10*10 m initially was subsequently reduced to 7.5*7.5 m and finally to 5*5 m to improve the accuracy of the estimates. Similarly the sampling fraction was slowly increased from 10 % to 15 % and finally to 20 % with the reduction in size of the districts.

After 1999-2000, when the size of some of the district became very small and the processing speed increased many times, we switched over to complete enumeration approach. In this approach the satellite data for each district was extracted by overlaying the administrative district boundary and analysis of the data for the entire district was done.

4.2 Digital analysis

In season ground truth was collected by approaching each selected segment of the district. Satellite data was acquired at the peak vegetative stage of the crop. Satellite data was rectified and registered with respect to Survey of India topo-sheets.
Digital analysis was carried out using Supervised Classification and Maximum Likelihood (MXL) algorithm. In this approach the training statistics was generated after feeding the ground truth collected. Based upon the training statistics the wheat pixels were classified for each district which were converted to area. Wheat area in the district was computed by applying the area correction factor for the district.

4.3 Yield Modelling

Initially the yield estimates for each district were provided based upon trend analysis of the historical yield data collected from Department of Agriculture. Subsequently, when database on the Vegetation Index of each district for 5-6 years was generated, multiple regression models including trend predicted yield and VI were developed, which increased the accuracy of estimates for most of the districts. Finally Zonal-spectral-trend yield models were developed using agro-meteorological indices like accumulated rainfall, minimum temperature, maximum temperature and growing degree days (GDD) etc. The meteorological data was available only for the four different regions of the state. These models further improved the accuracy of the estimates.

5 RESULTS AND DISCUSSION

5.1 Acreage Estimation

The area estimates of wheat were provided in the beginning of the project at the state level using

Landsat MSS data. Subsequently, area estimation at district level was initiated.

Figure 2 provides the wheat area in the state estimated using Remote Sensing (RS) data in comparison with Bureau of Economics and Statistics (BES) estimates since the beginning of the project.

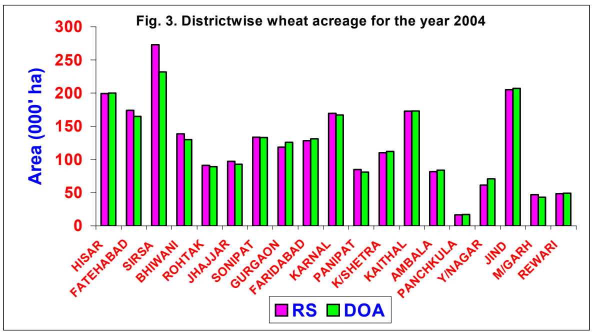


Fig. 3. Districtwise wheat acreage for the year 2004

It is clearly visible from the figure that their exited wide gaps between RS and BES estimates at the start of the project. However, with the improvement in methodology the difference in the two estimates narrowed down and currently we have a difference of 2-3 % at the state level. District-wise estimates for the year 2004 are provided in Figure 3. At district level the difference in the RS and field based Department of Agriculture (DOA) estimates range from 3-5 % except

for Sirsa district where it is about 10 %. The difference is more in the south-western districts of Sirsa, Fatehabad and Bhiwani where the mixing of crop is more compared to central and northern districts. It is clear from the results that wheat acreage at state and district level can be estimated using satellite data with fairly good accuracy.

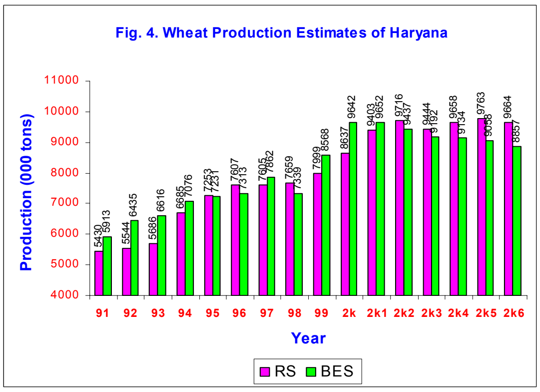


Fig. 4. Wheat Production Estimates of Haryana

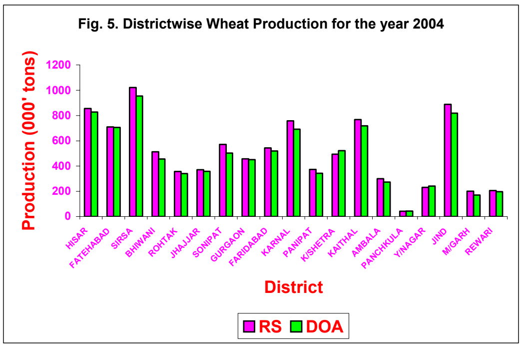


Fig. 5. Districtwise Wheat Production for the year 2004

5.2 Production

Production estimation was initiated in the year 1990-91 using trend predicted yield. Subsequently, yield was estimated using multiple regression models developed using spectral vegetation indices from satellite data along with meteorological and historical yield data as described in the methodology. Zonal Spectro-trend, Trend-agromet and Spectro-trend-agromet models for wheat production forecasting were developed for different regions of the state of which the last one gave the best results.

Zonal spectro-trend-agromet yield models developed for the year 2004 are as under:

Zone 1: Ambala Panchkula, Y/Nagar and Kurukshetra
$Y = -39.96 + 0.932\ GDD_1 - 0.567 ARF_6 + 0.801\ Yt - 1.662 VI$
$R^2 = 0.89$
Zone 2: Karnal, Kaithal, Jind, Panipat, Sonepat, Rohtak
$Y = -10.46 + 0.146\ TD_1 + 0.148\ TD_3 + 0.175 GDD_3 + 1.079\ Yt - 0.585 VI$
$R^2 = 0.92$
Zone 3: M/garh, Rewari, Jhajjar, Gurgaon, Faridabad
$Y = -11.46 + 0.045\ TD_6 + 0.28 ARF_4 + 1.04\ Yt - 3.391 VI$
$R^2 = 0.91$
Zone 4: Sirsa, Hisar, Fatehabad and Bhiwani
$Y = 13.768 - 0.217 GDD_4 + 0.138 GDD_7 + 0.16\ ARF_1 + 0.855 Yt - 3.101 VI$
$R^2 = 0.91$

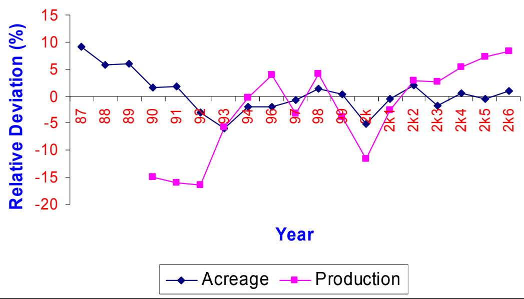
Where: VI = Vegetation Index	1. Crown root initiation stage
Yt = Trend predicted yield	2. Tillering stage
TD – Temperature Difference	3. Jointing stage
GDD – Growing Degree Days	4. Flowering stage
ARF – Accumulated Rainfall	5. Milking stage
VI = Vegetation Index	6. Dough stage
Yt = Trend predicted yield	7. Maturity stage

State level production estimates since the beginning of the project are provided in figure 4 and district level production estimates for the year 2004 are provided in figure 5. Results indicated that the difference in the RS and BES estimates have narrowed down over the years since the beginning of the project but not to the extent as in case of acreage estimation. This indicates that we still need to improve upon our yield models to make them more robust to predict the yield more accurately. Similarly, variation in the production at the district level are still more pronounced. This indicated that we need to have districtwise yield models in place of Zonal models to improve the accuracy of the estimates. Availability of the meteorological data at the district level is the main hurdle in developing such models.

5.3 Accuracy

The accuracy of the satellite-based estimates depends on the methodology adopted for interpreting and analyzing the satellite data. Relative Deviation (RD) of the RS estimates in comparison to DOA estimates, as provided in Figure 6, has significantly improved since the beginning of the project. Presently remote sensing technology is able to provide district level acreage and production estimates with 95 % accuracy.

Fig. 6. Relative Deviation of Wheat Estimates in Haryana



5.4. Timeliness

The crop forecasts to be really useful in the planning process need to be provided well before the harvest of the crop. Since the major objective of the current project was to operationalize the crop forecast, efforts were made to improve the timeliness of the forecasts over the years. Figure 7 indicates that the timeliness of the remote sensing wheat estimates have improved substantially over the years due to availability of efficient hardware/ software and high frequency of getting timely satellite data. The target dates for finalization of the wheat estimates i.e. the mid March is about a month in advance than the harvest of the crop i.e. mid April.

6.0 CONCLUSIONS

The accuracy and timeliness of the remote sensing estimates in comparison to BES/ DOA estimates has significantly improved since the beginning of the project. Presently remote sensing technology is able to provide district level acreage and production estimates much before the harvest of the crop with 95 % accuracy. Both the accuracy and timeliness of the estimates are likely to improve further with the availability of very high resolution (6 meter) satellite data through LISS-IV sensor of Resourcesat launched by India in October, 2003. This data may revolutionize the way agricultural systems are managed in the country. This high-resolution data could be used for the assessment of minor crops, horticultural and vegetable crops for which no information is currently available with the government or any other agency. Besides this satellite data would be helpful in carrying out various agricultural operations and optimization of agricultural inputs through the concept of precision farming. Following major research areas have been identified for improving crop production forecasts

- The research efforts related to yield models for forecasting, needs to be directed towards from the statistical approach to model based approach, which will use crop growth functions as well as model based crop parameter retrieval from satellite data (Dadhwal, 1999).
- The new procedures should incorporate operational atmospheric correction using the globally available geophysical derived products on ozone, water vapour and aerosols at coarse resolutions.
- With increasing availability of thermal infrared and microwave data, procedures for their use alone or in combination with optical- Near Infrared regions need to be adapted for operational yield modelling.
- Sensor-to-sensor and date normalization procedures need to develop when using data from any of the available sensors within-season or across-season for data analysis.
- Generation of locally developed LAI-NDVI model for the satellite data is one of the important input in the wheat simulation model WTGROWS. This NDVI-LAI relation then is inverted to compute RS based LAI estimates. This suggests a need to develop an easy to use LAI retrieval procedure from satellite data.

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