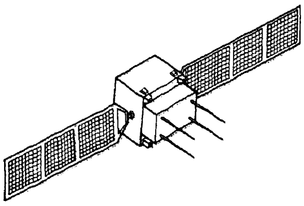

Special issue on:
Remote Sensing for National Development

Crop Inventory using Remotely Sensed Data

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ABSTRACT: *The physical basis of crop identification/discrimination and estimating its yield using spectral data is described. State-of-the-art crop inventory has been summarised. Development of methodology for acreage, condition assessment and yield forecasting using RS data are discussed. Results obtained for major crops in India using digital data from the Indian Remote Sensing Satellite-1A are presented. The pre-harvest estimation of wheat, rice, cotton, sorghum, oil seeds and mulberry are promising and demonstrate the capabilities of remotely sensed data from IRS-1A and other satellites. These studies relate to the chosen districts in Andhra Pradesh, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal with wide variations in soils, climatic conditions and management practices. Limitations of the techniques are indicated and scope for improvement has been outlined.*

INTRODUCTION

Agriculture is the backbone of Indian economy, contributing about 40 per cent towards the Gross National Product and providing livelihood to about 70 per cent of the population. The total geographical area of the country is 329 m ha, out of which 142 m ha is net sown area and 182 m ha is gross-cropped area. Foodgrain production has increased from 51 million tons in 1950 to about 170 million tons in 1990. India's population, which stands at 840 million (1991 census) is expected to reach the staggering figure of one billion by the year 2000 AD. Foodgrain requirement for 2000 AD is estimated to be around 230 million tons. If the challenge of feeding, clothing and providing other necessities of life to the growing population is to be met, better management of land and water resources is a must. Remote sensing (RS) techniques have demonstrated their potential in providing information on the character and distribution of various natural resources. Possible application areas related to agriculture are ...nt of land and water resources, crop ... forecasting, and assessment of the ...aused by floods, drought, crop epidemics, ... current status of remote sensing applications in various areas mentioned above are discussed by Sahai and Ajai[1] and Sahai and Dadhwal[2]. The present paper deals with the application of remote sensing to crop production forecasting.

CROP PRODUCTION FORECASTING

Scientific Rationale

Crop production forecasting comprises identification of crops, acreage estimation and forecasting their yield. Crop identification and discrimination is based upon the fact that each crop has a unique spectral signature. Typical spectral reflectance of a crop shows absorption due to pigments in the visible region (0.4 to 0.7 m), high reflectance in the near infrared region because of internal cellular structure of the leaves, and absorption at 1.45, 1.95 and 2.6 m spectral bands due to water content. Spectral response of a crop canopy is influenced by (i) the leaf-area index (LAI) and per cent ground cover, (ii) growth stages, (iii) differences in cultural practices, (iv) stress conditions, and (v) canopy architecture. Background soil/water is an important influencing factor. Each crop has its own architecture, growing period, etc. thus enabling discrimination through RS data. If there are two crops with similar spectral signatures on a given date (confusion crops), multi-date data may be used to discriminate them. Vigour of the crop is manifest in the absorption in the red and reflectance in the near infrared. It has been observed that the ratio of near infrared to red radiance is a good indicator of the vigour of the crop. Some of these properties are utilised in crop identification, yield forecasting and crop condition assessment.

STATE OF THE ART

The Corn Blight Watch Experiment initiated in April 1971 evaluated the use of high altitude aerial photography to detect corn blight and its spread. One of the first experiments carried out using Landsat-1 data was Crop Identification Technology Assessment for Remote Sensing (CITARS). It aimed at identification of two major crops, corn and soybean, and testing the concept of signature extension. Large Area Crop Inventory Experiment (LACIE) carried out during 1974–78 was a major international study carried out in major wheat growing areas of the world. It used Landsat MSS data for wheat acreage estimation and agro-meteorological models for yield estimation. LACIE results were best for USSR, but for studies in US Great Plains, Canada, India, China, Australia, Brazil and Argentina, though encouraging, did not meet the accuracy goals. Agriculture and Resource Inventory Surveys through Aerospace Remote Sensing (AgRISTARS) programmes initiated in 1980 in the United States was a follow-on research activity. USDA Statistical Reporting Service (SRS) has integrated Landsat data in the domestic crop estimation programme. One of the early studies undertaken using Landsat MSS data to identify rice and estimate its acreage was carried out by the Commission of European communities in collaboration with several specialised national institutes. Details of these experiments are discussed in the chapter on Remote Sensing Applications in Agriculture, Manual of Remote Sensing; Vol. II and in various references cited therein[3].

Identification of root-wilt disease in coconut using aerial false colour photographs in 1970 was the pioneering experiment in India[4]. Agricultural Resources Inventory Survey Experiment (ARISE) was carried out jointly by ISRO and ICAR in Anantapur district of Andhra Pradesh and in Patiala district of Punjab to estimate acreages under various crops using aerial colour infrared (CIR) photography. In another experiment conducted in Karjan (Gujarat), it was not only possible to identify four varieties of cotton, but also to delineate four vigour classes on CIR imagery. Results of various aircraft and ground-based experiments carried out for crop-related studies are summarised by Navalgund and Sahai[5]. Under the IRS Utilisation Programme initiated by Department of Space in 1984, different aspects of the problem of crop inventory using RS data were studied[6]. Systematic plot-level experiments were carried out on wheat and rice to understand their spectral behaviour and to develop empirical yield models using spectral data. Concepts developed have been later used to estimate yield using spaceborne RS data. The first attempt in the country towards the use of satellite digital data for wheat acreage estimation was made in Karnal district of Haryana using Landsat MSS data by Dadhwal and Parihar[7]. A project on Crop Acreage and Production Estimation under the Remote Sensing Applications Mission with enlarged scope and objectives was formulated in 1986. A concerted effort has been made under this programme to develop methodology applicable over large areas. The crops studied include wheat, rice, sorghum, groundnut, rapeseed/mustard and cotton.

ACREAGE ESTIMATION

Identification and discrimination of various crops/land cover classes require quantitative use of subtle differences in their spectral data, and hence rely mostly on digital image processing techniques. The acreage estimation procedure broadly consists of identifying representative sites of various crops/land cover classes on the image based on the ground truth collected, generation of signatures for different training sites and classifying the image using training statistics. Most of the work carried out so far has used single-date data corresponding to the near maximum vegetative growth stage of the crop. District level acreage estimation has been generally carried out by analysing the complete data. In this case, the administrative boundary of the district is digitised, a mask is generated and superposed on the scene. All the data elements (pixels) within this, are extracted for further analysis. Either all the pixels are classified or a systematic sample is used for supervised maximum likelihood procedure[8]. Such a procedure has been successfully used for wheat, rice, sorghum, oilseeds and cotton in many districts of various states. Mulberry acreage estimates have been attempted at taluk level.

Estimation of crop acreages for large areas, like states requires handling of a very large volume of data, larger efforts in ground truth data collection, etc. In such a case, it will be difficult to complete the entire data analysis in the short time available

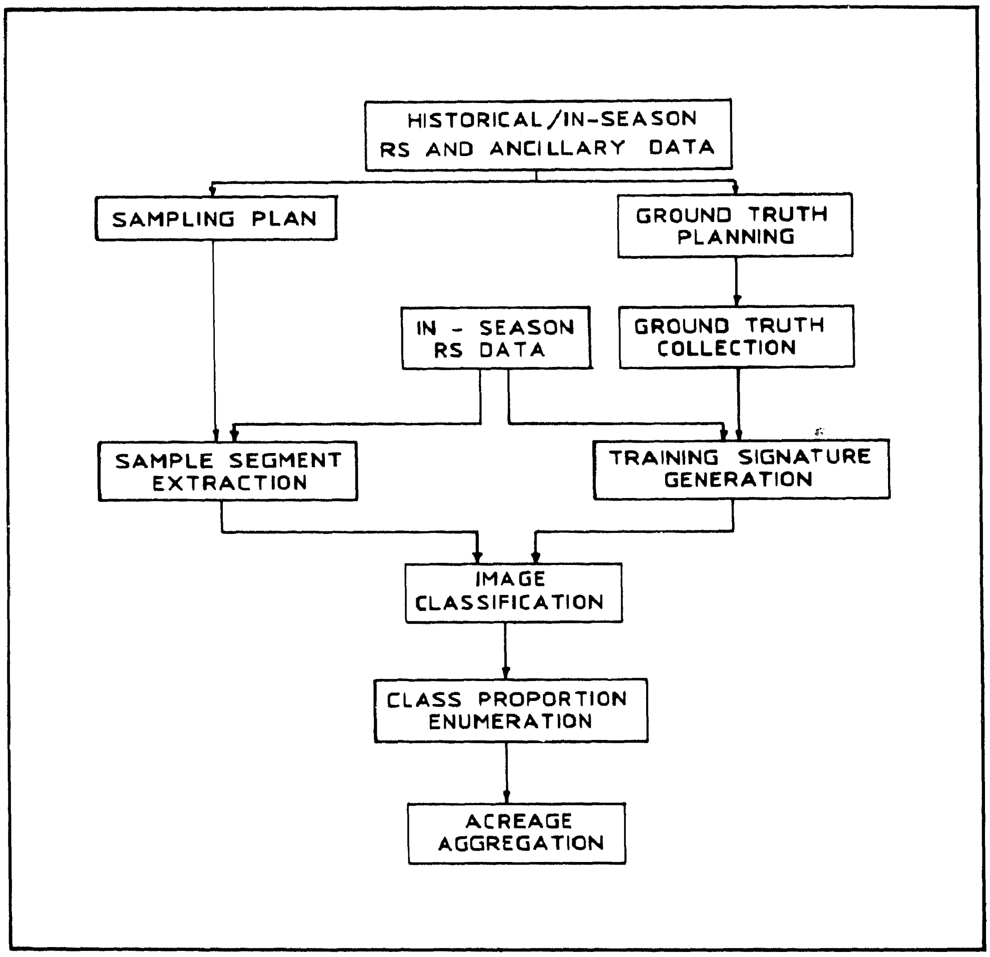

Figure 1. Procedure for acreage estimation using sampling techniques.

and provide preharvest estimates. To overcome this problem, sampling technique based procedures have been developed and successfully used (Figure 1). Based on the crop concentration statistics, agrophysical and/or agroclimatic conditions, the study area is divided into homogeneous strata. Each stratum is divided into segments each of 10 km x 10 km size. Segment sizes of 7.5 km x 7.5 km and 5 km x 5 km are also being tried for heterogeneous areas. Further stratification is done on the criterion of a sample segment having more than fifty per cent agricultural area or less. For digital data analysis, generally ten per cent of the total population is used. Second level stratification has been attempted using in-season data either by visual techniques or with near infrared to red ratio digitally[9]. Appropriate statistical methods are employed to aggregate results at stratum and study area/state levels[10].

FORECASTING

... a large number of factors ..., soil characteristics, cultural ... irrigation, fertiliser), weather ... influences, such as weeds, diseases and pests, etc. Spectral data of a crop is an integrated manifestation of the effect of all these factors on its growth. The two approaches adopted for yield modelling using RS data are (i) RS data or derived parameters which are directly related to yield, and (ii) RS data which is used to estimate some of the biometric parameters, which in turn are input parameters to a yield model. Spectral index of the crop canopy (NIR/Red, Greenness, NDVI) at any given point of time reveals the crop growth and its decay as affected by various factors in the time domain. The analytical form suggested by Badhwar[11] for a greenness[12] profile is shown in figure 2. The nature of the curve remains the same when greenness is replaced by any spectral index involving near infrared and red radiance of a crop.

$$G_{(t)} = G_0 (t/t_0)^{\alpha} \exp\beta\,(t_0^2 - t^2) \quad t > t_0$$

$$G_{(t)} = G_0 \qquad \text{for } t \leq t_0$$

Where $G_{(t)}$ is the spectral index at time t expressed in days after sowing, G_0 refers to soil greenness, t_0 is the date of spectral emergence, whereas α and β refer to growth and decay of the plant. Profile parameters may be related to physiologically significant processes and hence

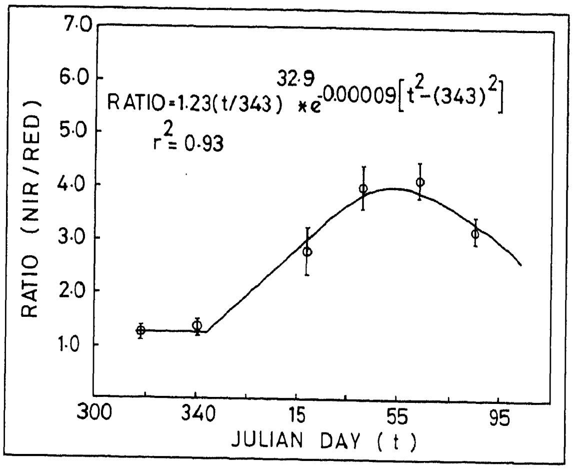

Figure 2. A typical growth profile for wheat.

yield. For example, maximum Leaf Area Index (LAI) during peak vegetative growth (t_0) is analogous to the peak value of the crop growth profile curve (G_m). Area under the profile can be considered analogous to the total photosynthetic period of the crop. Full width at half maximum (FWHM) of the profile can be considered to represent photosynthetic duration (leaf area duration). Rate of senescence can be thought of as average slope of the profile in post-heading time domain. Efforts have been made to develop a relationship between yield and spectral index using spaceborne data at maximum vegetative cover, and also using different parameters of the profile. The two approaches feasible for this are (i) single date spectral approach, and (ii) growth-profile approach.

(i) **Single date spectral index approach:** Various steps adopted in this approach are given in figure 3. Two corrections found extremely important in deriving a yield model are: (a) correction for different dates of data acquisition using a growth profile (Figure 2), and (b) Sensor-to-sensor transformations for radiances (Figure 4). Historical yield values obtained using crop-cutting experiments are used in developing regression relation[13].

(ii) **Growth profile approach:** The spectral growth profile approach provides complete information on the canopy development. However, 16/22 day repetitivity of Landsat/IRS do not provide sufficient temporal resolution to obtain growth profiles. NOAA-AVHRR provides an opportunity

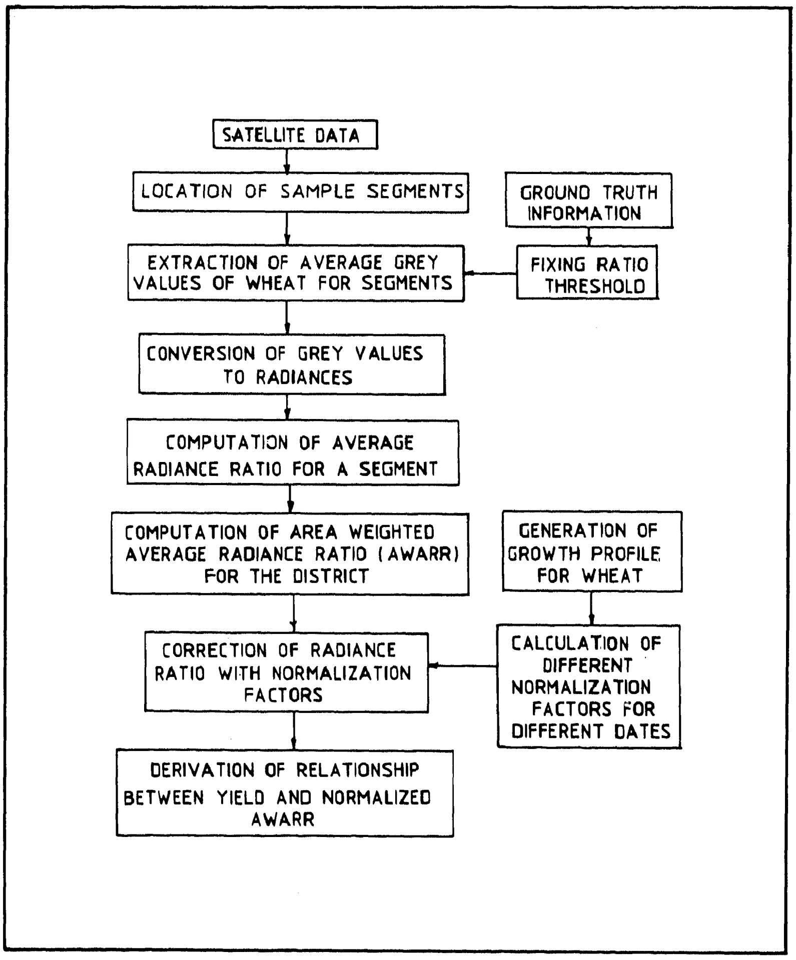

Figure 3. Various steps involved in RS data-based yield forecasting.

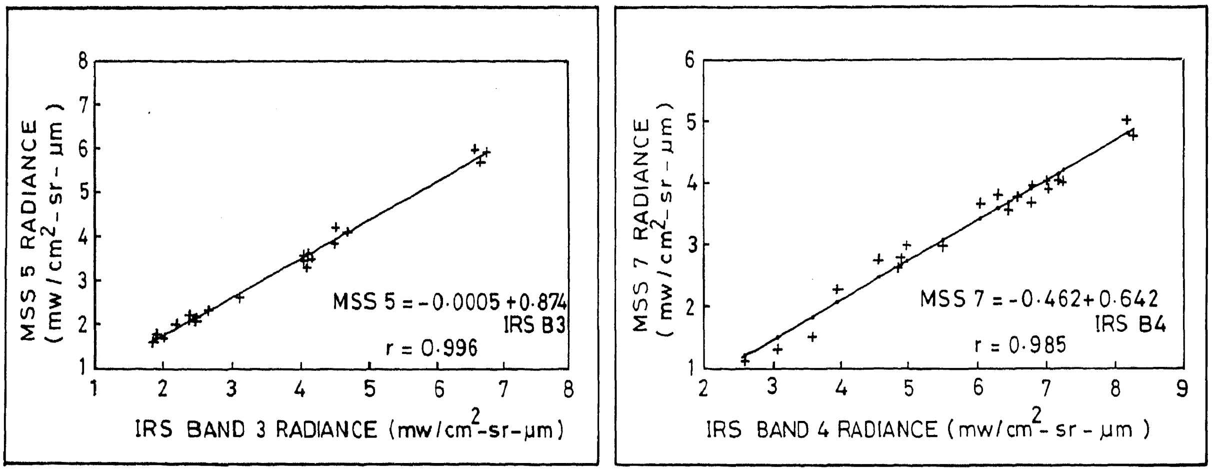

Figure 4. Plot of spectral radiance values of various surface features as measured by Landsat MSS (Feb. 11, 1989) and IRS-1A LISS-I (Feb. 10, 1989).

for such an attempt, although spatial resolution is coarse for crop identification. Using multidate NOAA-AVHRR data of Punjab and Haryana, various wheat growth profile parameters were derived and yield models developed. The 'AREASUM', area under the profile curve showed high correction with yield[14].

$$Y = 18.17 + 0.695 \text{ AREASUM } (r = 0.82, F = 37.4)$$

Condition Assessment

Condition of the crop is affected by factors, such as supply of water and nutrients, insect/pest attack, disease out-break and weather conditions. These stresses cause physiological changes, which may alter the optical properties of leaves and bring about changes in canopy geometry. The task of crop con-

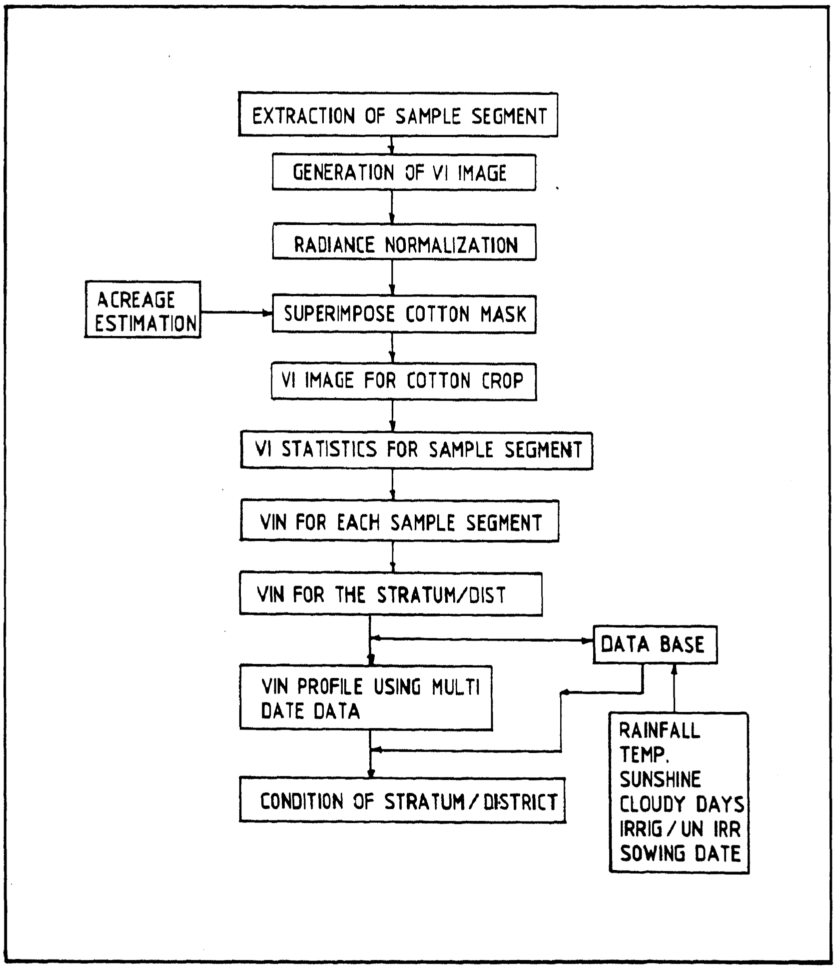

Figure 5. Procedure for crop condition assessment.

dition assessment requires (i) detection of stress, (ii) differentiation of stressed crop from the normal crop at a given time, (iii) quantification of extent and severity of stress, and (iv) assessment of the production loss. Condition assessment is normally done on a grid-cell basis using multiband satellite data. The area of interest is divided into geographically referenced grid cells of appropriate size, and each grid is monitored individually[15]. Various steps involved in the crop condition assessment procedure used for cotton crop are given in the flow diagram (Figure 5). Vegetation Index (VI) for the pixels of the crop of interest are computed for the selected sample segments and VI statistics are generated. The VI is either tasseled cap greenness, near IR to red radiance ratio or normalised difference vegetation index (NDVI). Greenness is expressed as:

Greenness =

$- 0.172\ B1 - 0.1219\ B_2 - 0.4341\ B_3 + 0.8861\ B_4$,

where, B_1, B_2, B_3, B_4 are digital counts in four bands of IRS LISS-II data, respectively.

From the VI computed for each pixel in the cell, vegetation index number (VIN) is computed for each segment for different dates. From these, VIN profile is generated and stored in a data base to carry out trend analysis.

SPECIFIC CROP INVENTORIES

Wheat

The states of Punjab, Haryana, 24 districts of Western Uttar Pradesh, 9 districts of Eastern Rajasthan and 8 districts of Central Madhya Pradesh, together covering a geographical area of 36.26 m ha and accounting for 60 per cent of the total wheat production of the country, are considered for wheat acreage estimation. Sampling plan was designed to give acreage estimates at the state level, but was later modified to provide district level figures as per the users demand. Results of RS-based acreage estimates are given in table 1. Improvement in the confidence limit observed over the years is due to better sampling plans and more detailed and segment-specific ground truth data collection. It has also been possible to advance the date of estimates over the years. For the 1990–91 season, wheat estimates were available on March 16, 1991 for Punjab and Haryana, almost a month in advance of harvest. Some of the yield models developed are:

Punjab : $Y\ (q/ha) = - 0.53 + 71.03\ NDVI$

$r = 0.83$, $F = 69.1$, $SEOE = 2.48$
(1987–88, 1988–89 & 1989–90)

Table 1. Results of RS-based wheat and rice acreage (in ’000 ha) estimation

		Pre -IRS PHASE		IRS PHASE			
		1985–86	1986–87	1987–88	1988–89	1989–90	1990–91
Wheat	Punjab	– –	2840 ± 197 (2795)	3042 ± 189 (3126)	3128 ± 171 (3156)	3108 ± 106 (3246)*	3243 ± 95
	Haryana	2094 ± 239 (1699)	1960 ± 195 (1784)	1855 ± 162 (1747)	1938 ± 159 (1820)	1917 ± 90 (1885)*	1840 ± 83
	Uttar Pradesh	–	1647 ± 76 @ (1392)	1378 ± 105 @ (1350)	4105 ± 235 # (4173)	2465 ± 91** (2277)	3330 ± 75.5***
	Madhya Pradesh++	–	–	–	727 ± 90 (1202)	1128 ± 165 (1110)	1050 ± 40
	Rajasthan++	–	–	–	1370 ± 170 (880)	940 ± 160 (870)	882.8 ± 72.60
Rice	Orissa+++	–	5290 ± 220 (4200)	–	3919 ± 217 (4088)	3926 ± 244 (4187)	–
	Tamil Nadu##	–	–	–	–	1519 ± 163 (1488)	–
	West Bengal###	–	818 (768)	–	–	–	–

* First Estimates
@ Seven districts
\# 24 districts
** Fourteen districts
++ Eight districts
*** 19 districts
+++ Kharif rice
\## Samba
\### One district

(Figures in parenthesis are from the Bureau of Economics and Statistics)

Haryana : $Y\ (q/ha) = -1.52 + 16.54\ AWRR$
$r^2 = 0.67 \quad SEE = 2.41$

Using these simple first degree equations and computing the Average Weighted Radiance Ratio (AWRR) or NDVI as the case may be, district level yields are forecast. Individually districts showed 8–10 per cent deviations. The state level production figures are given in table 2.

Table 2. Wheat production estimates 1990–91

State	Acreage		Production	
	M ha	CV%	M tons	CV%
Punjab	3.244	1.78	12.376	2.74
Haryana (except Gurgaon)	1.795	2.76	5.305	3.52

Rice

Orissa and Tamil Nadu states account for 18 per cent of rice production in the country. In Orissa, it is predominantly a rainfed crop, while in Tamil Nadu it is predominantly irrigated. In addition to these states, work has also been carried out for rice in Midnapur district of West Bengal[16], and for Basamati rice area estimation in Karnal district of Haryana. Stratified sampling has been adopted for state level acreage estimation (Table 1). It has been found that the sample segment approach adopted is flexible enough to use multi-satellite data in case of cloud cover problem[17,18]. Yield model developed for rice for coastal Orissa is :

$$Y\ (q/ha) = -21.01 + 22.32\ AWRR,\ r^2 = 0.52,\ RMSE = 2.62$$

In the case of rice, diversity in growing conditions as well as yield is much higher. Spectral indices are sensitive to the water background, particularly in cases where the rice canopy is poor. In such a case, smaller administrative units such as blocks have been considered for deriving a spectral index-yield relationship[19].

Sorghum

Sholapur, Pune and Ahmadnagar districts of Central Maharashtra, which account for 41 per cent of production and 50 per cent of area under sorghum of the state of Maharashtra have been chosen for crop area estimation. Use of atmospherically corrected data has shown that it improves crop discrimination[20]. Higher radiometric sensitivity and higher signal/noise (S/N) ratio obtained with IRS LISS-I data over Landsat MSS has helped in achieving better accuracies in a dryland crop like sorghum. Rabi sorghum acreage results for 1990–91 are given in table 3. The yield model developed for sorghum for Central Maharashtra is:

$$Y\ (ton/ha) = -1.75 + 13.72\ NDVI - 17.1(NDVI)^2, \quad r^2 = 0.96\ RMSE = 0.073$$

Table 3. Rabi Sorghum acreages using IRS LISS-I Data (1990–91)

Taluk/District	RS acreage ('000 ha)	Dates of data acquisition	Date of completion
Sholapur	809.6	Dec. 22, '90	Jan 23, '91
Pune	472.5	Dec. 23, '90	Jan 23, '91
Ahmadnagar	516.4	Dec. 23, '90	Jan 23, '91
Hungund (Bijapur)	51.41	Jan. 12, '91	–

Oilseeds

Junagadh, Amreli and Rajkot districts accounting for 65 per cent production of groundnut from Gujarat, are identified as the study districts. Approach adopted comprises preparation of vegetation mask, systematic sampling and supervised classification. Six districts of Rajasthan and two districts of Gujarat[21] have been taken up for rapeseed/mustard acreage estimation. Results are given in table 4.

Table 4. RS Estimates for mustard/rapeseed during Rabi 1990–91

State	District	Acreage in ('000 ha)
Rajasthan	Alwar	246.00 ± 36.8
	Bharatpur	212.90 ± 22.6
	Dholpur	70.70 ± 15.9
	Jaipur	139.30 ± 27.2
	S. Madhopur	137.10 ± 18.3
	Tonk	80.10 ± 24.4
Gujarat	Banaskantha	160.48 ± 15.9
	Mehsana	162.14 ± 11.7

Cotton

Seventeen major cotton growing districts covering 1,65,068 sq. km area distributed in six states have been taken up. IRS LISS-I data for 1990–91 crop season were used. Stratified random sampling approach was followed with segment size of 7.5 km

Table 5. Cotton Acreage Estimates using IRS LISS-I data (1990–91)

State	Districts	RS Estimates ('000 ha)	BES Estimates ('000 ha)
Maharashtra	Amravati	337.11 ± 30.64	368.90
	Buldhana	292.27 ± 19.07	242.60
	Akola	290.59 ± 18.76	319.30
	Wardha	172.42 ± 16.91	167.40
	Yavatmal	380.60 ± 30.70 +	441.69
Haryana	Sirsa	181.9 ± 13.80	163.10
	Hissar	262.75 ± 30.10	230.00
Punjab	Bhatinda	265.25 ± 19.97 *	
	Faridkot	207.89 ± 12.90 *	225.00
	Firozepur	103.78 ± 1.08 *	129.00
	Sangrur	67.17 ± 16.00 *	83.00
Andhra Pradesh	Guntur	154.52 ± 10.25	156.13
	Prakasham	34.58	37.16
	Adilabad	125.2	143.90
Madhya Pradesh	Khandwa	171.34	146.00
	Khargone	161.44 ± 22.06	191.00
Gujarat	Surendranagar	153.36	156.46

* Landsat MSS data was used. + LISS-II data was used.

x 7.5 km and using maximum likelihood classification procedure. The estimated acreages for the 17 districts are given in table 5. Figure 6a shows IRS LISS-I FCC for Bhatinda district of Punjab and the classified image for the same area is shown in figure 6b.

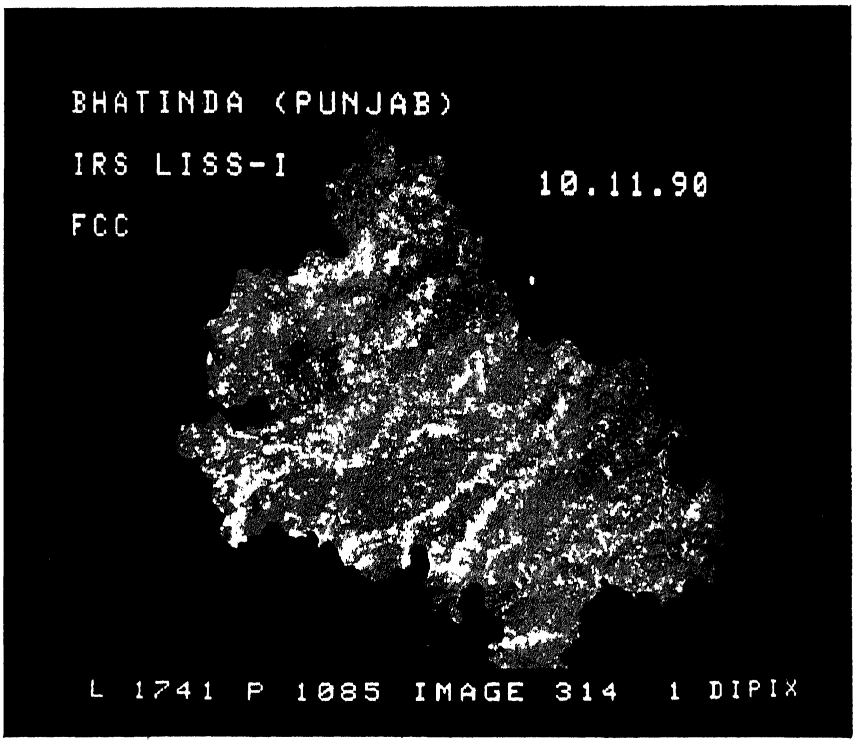

Figure 6a. False colour composite covering Bhatinda district of Punjab.

Figure 6b. Classified thematic image of Bhatinda district showing cotton areas in green and fallow fields in red tone.

Table 6. Mulberry acreage estimates using IRS-1A data and comparison with other sources

Source of acreage estimates	Taluk (District)	
	Malavalli (Mandya)	Yelandur (Mysore)
	(Area in hectares)	
RS estimates	7673	2541
Department of Sericulture estimates	7948	3023
Proforma returns from Sericulturists, TSCs and SDs	5502	2468

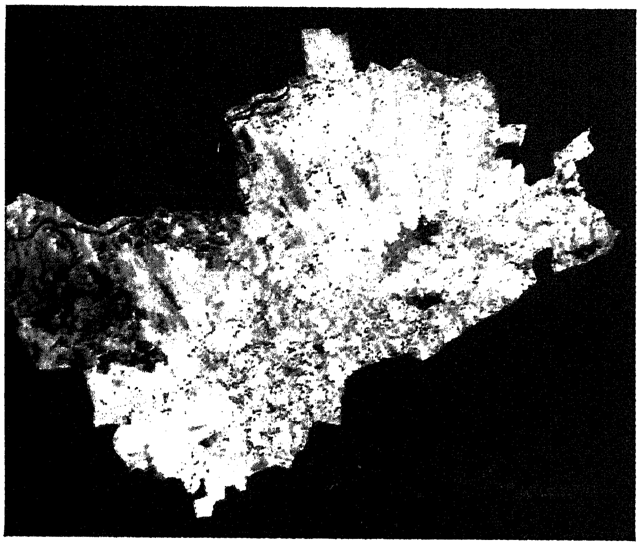

Figure 7. Mulberry crop inventory using IRS-1A data for Malavalli taluk of Mandya dist., Karnataka. Mulberry crop is shown in green colour.

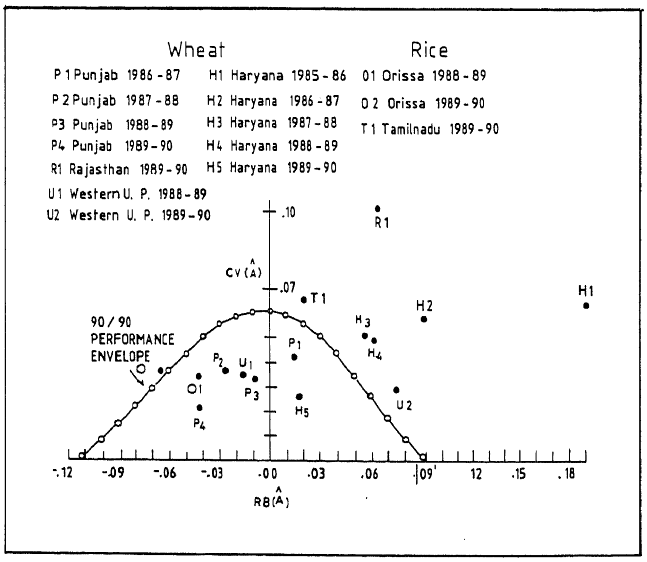

Figure 8. Evaluation of RS-based acreage estimates against 90/90 accuracy goal. CV : coefficient of variation; RB : Relative bias.

Mulberry

Malavalli and Yelandur taluks of Mandya and Mysore districts respectively are the study areas. Estimates are given in table 6 and the classified image is shown in figure 7.

Present achievements and future prospects

Work carried out so far in the country has amply demonstrated that by using single-date satellite data of a suitable date during the crop-calendar, it is possible to estimate pre-harvest acreages of major crops in single-crop-dominated regions with sufficient accuracy. Results have been evaluated against the 90/90 accuracy goal as evolved during LACIE programme[22]. Figure 8 shows that, over the years, methodology has improved and accuracy goals are met in many cases at state level. Some of the efforts to improve accuracies are:

- Better sampling techniques,
- More detailed/specific ground truth data collection,
- Use of data of other spectral regions (middle infrared) and higher spatial resolution, and
- Procedures involving more than single-date data.

Yield estimation studies conducted so far are confined to single-crop dominated regions and have mostly used single-date data. Development of models using growth profile parameters and incorporation of agrometeorological information in the simple spectral yield models are some of the research areas. Among the various factors determining crop classification accuracies, the placement, width and number of spectral bands of the sensor play an important role. The spectral bands chosen on IRS-1A have been ideal for vegetation-related applications. Availability of IRS-1A data in two spatial resolutions with identical spectral resolutions has offered unique advantages for crop studies.

As far as crop studies are concerned, one of the disconcerting factors of IRS-1A data has been its 22-day repetitivity. This lacuna is expected to be overcome with the launching of an identical IRS-1B satellite, perhaps in tandem with IRS-1A. The two proposed sensors onboard the IRS-1C (expected to be launched by 1994 or about), the LISS-III with additional band in the middle infrared and Wide Field Sensor (WIFS) with 4–5 days repetitivity will undoubtedly enhance the utility of IRS data for crop production forecasting.

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