MM 2.4 : Refining Regional Level Prediction of Cotton Production

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Targets	Achievements
Field experimentation to determine genetic coefficients	Field experiments were conducted with Bt and non-Bt hybrids, varieties with 2 dates of sowing under rainfed as well as irrigated condition across the cotton growing zones.
Collection of crop parameters	Crop phenology in terms of days required for emergence, squaring, flowering, boll bursting and maturity, leaf area index, biomass and its component parts (stem, leaf, fruiting parts, shed leaf wt and shed fruiting parts) were recorded at every 15 days interval. At the end seed cotton yield , boll number and boll weight of net plot was recorded.
Collection of soil and weather data	The weather data and soil properties of the experimental station and rainfall data of all the rainguage sites of Nagpur, Sirsa, Dharwad and Baruch districts were collected.
Model calibration	INFOCROP – model has been calibrated to simulate the growth and yield of Bt and non-Bt hybrids under both dryland and irrigated condition.
Model validation	Model was validated using data from different locations, years, hybrid, varieties, dates of sowing, levels of fertilizer, rainfed and irrigated conditions. Model validation was also done using on farm field trial experiments.
Integration of INFOCROP with GIS	The soil map digitization of Nagpur, Sirsa, Dharwad and Baruch districts were completed based on soil properties and rainfall pattern. An interface between the model and GIS was developed.
Ground truth observation in Nagpur distrct	The cotton area derived from the satellite data and soil classification into different depths based on GIS, is being confirmed by ground truth measurement. For this purpose in Nagpur district 32 farmers sites of shallow, medium and deep soils have been identified and their latitude, longitude, biomass and yield data were recorded.
Delineation of total cotton area of Nagpur, Dharwad, Sirsa and Baruch district	Using spectral signatures at red and green region obtained from satellite, the total cotton area of Nagpur Dharwad and Baruch districts was estimated. Cotton area in these districts has been classified based on soil depth and soil texture.
Integration of of soils and weather component with RS data using GIS (Arcview) technique.	The total cotton area derived from the satellite of Nagpur, Sirsa, Dharwad and Bharuch districts have been divided into polythesian polygons based on the soil texture, depth and rainfall information.
Prediction of cotton production using the integrated approach	Model was run to each of the polygons identified based on soil depth and soil texture properties of Nagpur, Sirsa, Dharwad and Bharuch districts. Yield of each polygon was summed up to get total production. Infocrop model was calibrated to simulate the actual yield without accounting for those losses due to insect pests. For Sirsa, Bharuch and Dharwad the model prediction of cotton production was good while for Nagpur the model had over estimated the yield.

Model calibration and validation

Field experiments were conducted at 4 cooperating centers with the main objective of generating genetic coefficients for Bt hybrids to be used for model calibration and validation. The experimental locations were CICR, Nagpur and GAU, Surat in Central Zone, CICR (RS) Coimbatore and UAS, Dharwad in Southern Zone. Popular Bt hybrid along with a conventional hybrid and a variety of the respective region was grown at two dates of sowing in a randomized block design at all the canters. Experiment was conducted both under rainfed and irrigated conditions.

The physical and chemical properties of the soil along with the moisture content were determined at regular intervals at all the experimental sites. Plant growth observations like leaf area index, stem weight, leaf weight and weight of fruiting parts were recorded at regular intervals.

Model calibration (CICR, Nagpur)

The field experiment data of Nagpur comprising date of sowing and genotypes was used for model calibration. Crop parameters such as phenological development, leaf area index, biomass accumulation and their partitioning into leaf, stem and fruiting parts, nitrogen accumulation and yield were estimated. Rest of the coefficients such as radiation use efficiency, light extinction coefficient, root extension growth, potential boll weight etc is collected from the literature. The genetic coefficients of different varieties used in the analysis of the model were estimated by repeated iterations until a close match between simulated and observed phenology and yield was obtained in these treatments. In order to understand the genotypic differences in water stress tolerance, the rooting pattern of tolerant and susceptible genotypes was measured. Tolerant genotypes possessed deeper more branched roots compared to susceptible genotypes. Genotypes with deeper roots withstood water deficit stress for a longer period while shallow rooted genotypes senesced faster and forcefully burst open all the bolls.

Infocrop-cotton model was calibrated to simulate the differential rooting pattern of the genotypes by changing the parameter RGRPOT. For a deeper rooted genotype the RGRPOT value was 15 while it was 12 for shallow rooted genotypes.

Flowering was first seen in Bt hybrid MECH 184 followed by RCH2 and other genotypes. Similarly, Bt hybrids in general matured early compared to non.Bt hybrids and variety. The simulated phenolgy showed a good match with the observed phenology.

The model simulated LAI and leaf weight followed the pattern of measured values up to peak growth (120 DAS) beyond which model simulated values declined slowly compared to measured LAI and leaf weight. Biomass on the other hand continued to increase beyond flowering because of the accumulation of seed cotton yield. Accurate estimation of biomass partitioned towards leaf beyond flowering in an indeterminate crop like cotton is complex under rainfed condition. New flushes keep emerging as and when rain comes or when some of the fruiting forms were lost either through physiological or entomological factors. Hence, model was calibrated to simulate biomass and yield accurately at reproductive phases.

Seed cotton yield ranged between 11 (PKV 081) to 20 q/ha (RCH 2 Bt) in normal planting while in late sown crop it ranged between 9.5 (PKV 081) to 13 q/ha (Bunny) . In fact, the seed cotton yield of late sown RCH 2 was the most sensitive, which the model accurately predicted.

Sensitivity analysis of INFOCROP-COTTON model to soil depth:

For sensitivity analysis, soil properties of Kokarda-9 (Typic haplusterts) series were used. Keeping the texture and other parameters constant, soil depth in the 3 layers was altered at 15 cm interval from an initial 15 cm to 195 cm and consistency in outputs were examined. Mean values of simulations over two years 2001-02 and 2002-03 are reported.

The consistency of output variables- days to maturity, seed cotton yield and dry matter production, simulated are presented (Table). The simulated yield increased linearly with depth up to 90 cm, plateaued later and there was a decline in yield beyond 150 cm.

Table1: Effect of soil depth on simulated days to maturity, dry matter and seed cotton yield

Soil depth (cm)	Maturity (days)	Dry matter production ($kgha^{-1}$)	Seed cotton yield ($kgha^{-1}$)	Soil depth (cm)	Maturity (days)	Dry matter production ($kgha^{-1}$)	Seed cotton yield ($kgha^{-1}$)
15	136	725	124	105	171	5630	1234
30	146	2458	427	120	175	5976	1260
45	152	3589	660	135	176	6196	1276
60	155	4318	857	150	175	6288	1238
75	159	4876	1047	165	174	6223	1228
90	166	5271	1213	180	174	6116	1219

This typically quadratic relationship between yield (Y) and soil depth (X) could be expressed as Y =2.022x-0.0007x^2-114.3 with an R^2 of 0.98. The increase in yield was accompanied by an increase in crop duration from 136 to 176 days (at 135 cm depth) and seasonal evapo-transpiration from 293 mm depth to 497 mm (at 150 cm).

Model validation

Characterization of the soils of on-farm (farmers' field) trials

Five topo sequences having shallow, medium and deep soils were selected in the villages of Kokarda, Kaniyadol and Pan-ubali in Kalmeshwar district of Nagpur district. The experimental sites were analysed and soil files were prepared using these values. In general, the productivity was low on shallow soils, intermediate on medium and high on deep soil. The differences within the depth category could be explained on the basis on textural variation.

Observed and simulated (INFOCROP cotton) seed cotton yield in onfarm trials

Soil	**Depth (cm)**	**MECH 184 Obs**	**MECH 184 Sim**	**Ankur 651**
Shallow	< 50	8.26	7.96	8.51
Medium	50-100	11.50	12.06	12.82
Deep	> 100	11.45	13.52	15.90

The simulated yield matched the observed values fairly well on shallow and medium deep soils but on deep soils, the yield was over predicted by INFOCROP-cotton model.

Spatial distribution of Cotton crop (NRSA & CRIDA - Hyderabad)

During 2006-07, analysis of satellite data to derive the information of the spatial distribution of cotton crop, overlay analysis of the soil and crop maps of Nagpur, Dharwad, Bharuch and districts were carried out.

Satellite (Resourcesat-1) data used in the study

District	Satellite/ Sensor	Date of pass
Sirsa, Haryana	Resourcesat-1 LISS-III	25-09-2006 30-09-2006
Bharuch, Gujarat	Resourcesat-1 LISS-III	30-12-2006 04-01-2007
Nagpur, Maharashtra	Resourcesat-1 LISS-III	05-10-2006 25-10-2006
Dharwad, Karnataka	Resourcesat-1 AWIFS	04-11-2005 18-11-2005 17-12-2005 05-01-2006 29-01-2006 27-02-2006

Each district was classified using total enumeration approach and spatial distribution of cotton crop was derived. Administrative boundary of the district was overlaid and the acreage was calculated.

Based on the availability of satellite imageries of Nagpur, Dharwar,Sirsa and Bharuch district and by superimposing the information on real time weather data from talukas, yields were predicted for different polygons of these districts and a combined estimation of production for the district was made.

Integration of soils and weather component

In order to integrate the information of spatial distribution of cotton crop as derived from the satellite data with the soil and weather parameters, GIS techniques were employed. Soil map prepared on 1: 2,50,000 scale by NBSS & LUP alongwith the poly thesian triangles based on the location of the station for weather parameters were provided in the form of a shape file by the Central research Institute for Dryland Agriculture (CRIDA). This shape file was converted into polygons in Arc GIS.

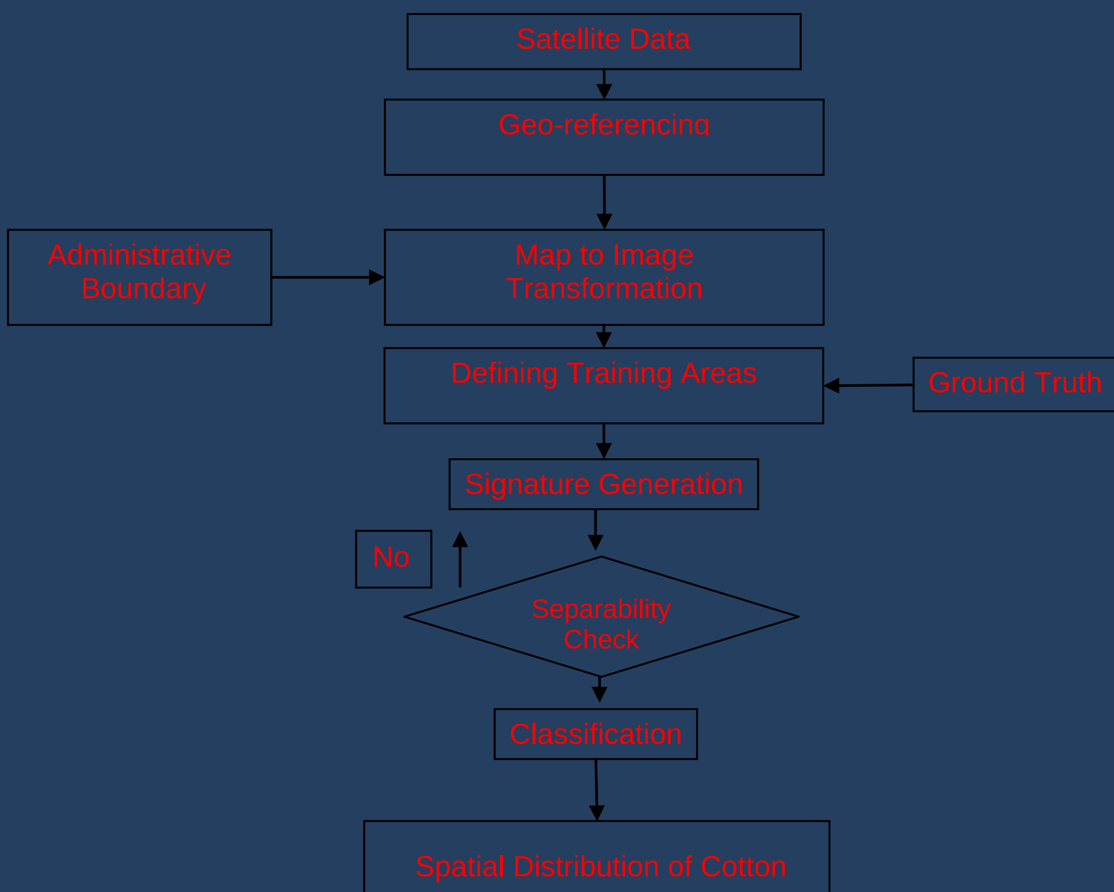
Nagpur district:

As per the NBSS & LUP soil map, six categories each of soil type and depth are represented. The soil maps are decomposed to generate soil depth and type maps separately and after overlaying the cotton vector, the area statistics of cotton in each of the attributes was derived.

Soil Depth

Six categories of soil depth were used in the generation of the soil map.About two-thirds of cotton crop of Nagpur district is grown on deep soils. Though very shallow soils are not congenial for cotton cultivation, yet about 22% of cotton is being cultivated on very shallow soils.

Digital analysis of remote sensing data



Soil Type

Distribution of cotton crop was found to be about two-thirds on fine textured soils. About 22% is distributed on coarse textured soils.These vectors were integrated to generate area statistics of cotton crop cultivated under

different soil depth, soil type regimes individually and across all combinations for each of the 9 polythesian triangles of Nagpur district. Yield computed for these different spatial domains of soil, varying in soil texture and type for a given polythesian triangle alongwith the cropped area statistics would provide the production at disaggregated level.
A combined analysis of the cultivation of cotton crop on different soil types and depths across the district was carried out. In this analysis, the per centage of association of a given soil depth with soil type were worked out. Further, proportion of the cotton area in each of these combined units was also worked out.

Dharwad district:
The soil map of Dharwad district prepared by NBSS & LUP on 1: 250000 scale has 6 categories each of soil texture and depth. Cotton cropped area statistics for all the categories independently and in association was generated after overlaying the cotton cropped area for each weather station.

Soil Depth
Six categories viz., very deep, deep, moderately deep, shallow, moderately shallow and very shallow are represented in the soil map. About 60% of the cotton is distributed on very deep to moderately deep categories.

Soil Texture
Five categories viz., calcareous clay, clayey, cracking clayey, gravelly clayey and gravelly loam soil textures are represented in the soil map. More than 90% of the cotton is distributed on fine textured classes that are more suited for cotton cultivation.
The model was run for obtaining the yield estimates for each of the soil type and depth category.

Bharuch district
An estimated area of 138439 ha is covered under cotton crop. About 80% of area is covered under clayey soil and the remaining is under loamy soil in this district. In terms of soil depth about 92% comes under deep soil and about 6.5% is under moderately deep soils and only 1.5% is covered under shallow soils.

Since there is a great deal of variability under fertiliser management, it was decided to study the influence of fertiliser doses under different soils and soil depths. Chosen dose of fertiliser include 120,240 and 360 kg/ha of urea.
The estimated yield for different soils and depths under varying doses of fertiliser indicate that increase in fertiliser dose from 240 to 360 kg/ha did not increase the lint productivity. Increase in dose of fertiliser from 120 to 240kg/ha also did not result in commensurate productivity improvements. The model was run for each of the soil type soil depth category for different fertilser dosages.

Sirsa district
Cotton crop in this district is grown under irrigated conditions. Crop is sown during end of April/ May. Copious amount of irrigation is given. Cotton crop in this district is grown under deep soils only. Cotton crop is grown under fine loamy, coarse loamy and sandy soils in this district. Out of an estimated 193000 ha, about 84000 ha is covered under coarse loamy soils. Another 82,000 and 25000 ha is covered under Sandy and fine loamy soils respectively. The model was run for three different dates of sowing i.e 121, 128 and 135 julian day and for diiferent soils with a single soil depth as deep.

Highest productivity was obtained under fine loamy soil conditions. Productivity is of the order of 2273 kg/ha of seed cotton. An yield of of 1850 and 1670 kg/ha was estimated for coarse loamy and sandy soils. Influence of soil depth on cotton yield was observed in case of coarse loamy and sandy soils than is fine loamy soils. Average seed cotton productivity is about 1829 kg/ha and lint productivity is about 723 kg/ha.

A survey was done in farmer fields independently to ascertain the productivity of cotton for different soils with in district. The survey indicated that an yield of 2202,2000 and 1642 kg/ha of seed cotton was obtained from fine loamy, coarse loamy and sandy soils respectively. The average lint productivity of the district is about 741 kg/ha. These results compare much favourably with model estimates.
Comparison of cotton productivity among four districts indicate that yield under irrigated conditions at sirsa district was much higher though the quantum of rainfall during the season is very low (300mm). On the other hand, though the quantum of rainfall is high in other districts 900-1300, this did not result matching yields with that of sirsa.

Probable reasons for variation could be

- Growing of crop in different environment setting i.e various soil depths and types
- Role of irrigation in assurance and thus ensuring sufficient input use.

On the other hand though rainfall is high, absence of information *a priori* on it's distribution during season did not enthuse farmers for sufficient supply of inputs for realising better crop.

The advantage of having these estimates based on the spatial variability of soil and weather is that one identify the growth performance of the crop with respect to soil type , taluq or soil depth and developmental programmes can identify the areas for developmental projects besides getting an estimation of production in advance based on the real time variability of weather and soils rather than a statistical based value for the district.

Methodology

Ground truth information and analysis of the satellite data are the two important steps involved in identification and delineation of cotton crop.

Ground truth

Detailed ground truth information was collected for identification and classification of cotton crop of the study districts. The False colour Composite (FCC) prints and SOI Toposheets covering the study area were used for collection ground truth. Based on the visual interpretation of the area, ground truth sites were marked on the FCC prints to enable to visit the field to collect intensive ground truth information on cotton and other crops. Ground truth information for Sirsa district was carried out during October, 2006. In case of Bharuch district, the ground information was collected twice during December and January months. Ground truth for Dharwad district was collected during mid January, 2006. During the field visits, information on cotton crop like sowing details, varieties, spacing, and crop stages along with details on other land cover classes was collected.

SATELLITE DATA ANALYSIS

Analysis of satellite data by complete enumeration approach using ground truth information was carried out for deriving spatial distribution and acreages of cotton crop. The analysis of satellite data was carried out using Geomatica image analysis software. The digital analysis of satellite data consists of georeferencing, co-registration, location of training areas, signature generation, classification and acreage estimation.

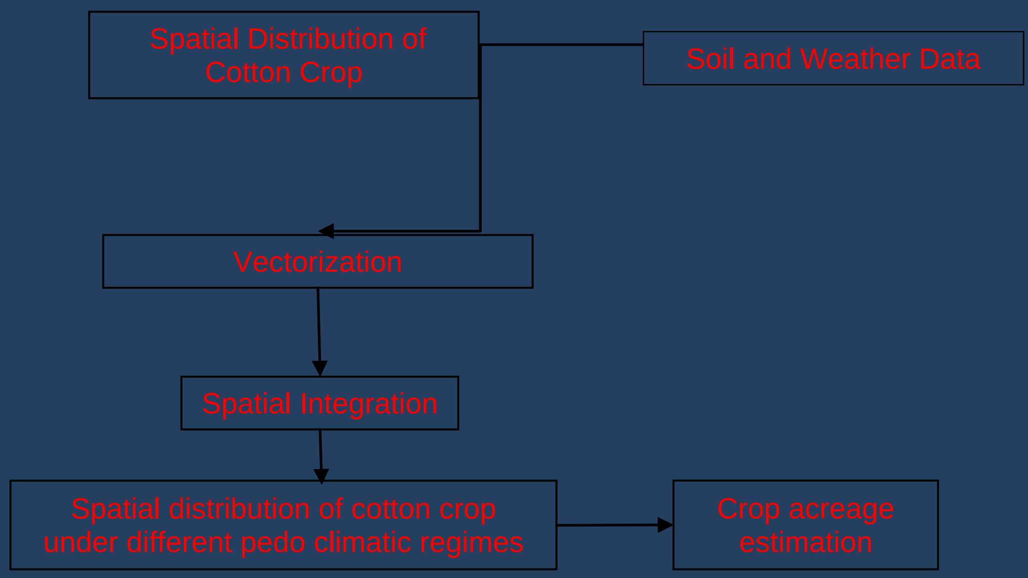
After loading the data, the sub areas pertaining to the study districts were extracted. First date data was registered to 1:250,000 scale survey of India toposheets using adequate number of ground control points. First order map-image transformation equation was developed and the image was resampled using nearest neighborhood algorithm. The various steps involved in the digital analysis of remote sensing data are shown in Fig-2. The georeferenced first date was used as master image for registration of subsequent dates data using image – image registration procedure.

The training windows were defined for cotton crop and other land use classes based on the ground truth information. Multiple training sites for each class were identified in order to represent the variability within the same class and final training classes were selected after achieving the separability among the classes by generating two band class ellipses for the training classes. The training area statistics in terms of mean, standard deviation and variance and covariance matrices were generated and the image was classified using supervised maximum likelihood algorithm. The district-wise crop acreages were estimated following complete enumeration method.

GIS ANALYSIS

Geographic information System (GIS) was used to integrate information on crop, soils and weather data. The spatial distribution of cotton crop in the vector format was integrated using ARC-GIS with the pedo-climatic data generated by NBSS-LUP. The acreage of cotton crop under each of the pedo-climatic zones was generated for further usage in crop modeling activity for generating cotton production under each of the pedo-climatic polygons to arrive at cotton production at district level. The detailed methodology is outlined in Fig-3.

Fig-3: Integration crop, soil and weather data using GIS



RESULTS AND DISCUSSION

Temporal LISS-III / AWIFS corresponding to kharif 2006 covering the four study districts namely Sirsa, Bharuch, Nagpur and Dharwad, were analysed for deriving spatial distribution of cotton crop. Based on the ground truth data, training areas for different agricultural land use / cover classes were defined and signatures were generated and the image was classified using maximum likelihood technique. The cotton crop map was converted to vector format and integrated with pedo-climatic maps to generate distribution of cotton crop under different pedo-climatic regimes.

Sirsa district

Cotton, rice and gaur are major crops of the district. The cotton crop is cultivated extensively and distributed throughout the district. The crop is well established covering the soil background completely during October month .

IRS LISS-III data of September 25 and 30, 2006 were used for discrimination of different crops of the study area for deriving distribution cotton crop in the district and acreage estimation The figure (Fig 1) indicates that the cotton crop was clearly manifested as red colour in September month data.

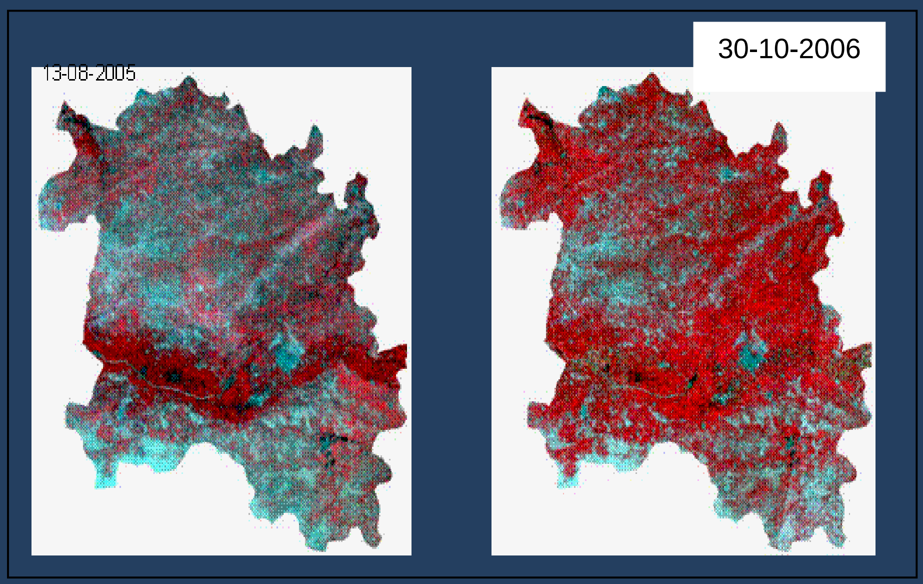


Fig 1: IRS LISS-III data of Sirsa district, Haryana

The satellite derived cotton crop distribution was integrated with soil map using GIS for generating distribution of cotton crop under different pedo-climatic regimes. Soil properties such as soil depth and soil types which are important for cotton cultivation were considered in the analysis. The spatial distribution of cotton crop under different soil types is depicted in Fig 2. The figure indicates that cotton crop is distributed in all three types of soils.

The satellite data analysis showed that the remote sensing based cotton crop acreage for Sirsa district was 1.98 lakh ha during 2006 season. It was observed that more than 40 per cent of the cotton crop was distributed in coarse loamy to sandy soils and 14.2 per cent of the crop was distributed in fine loamy soils.

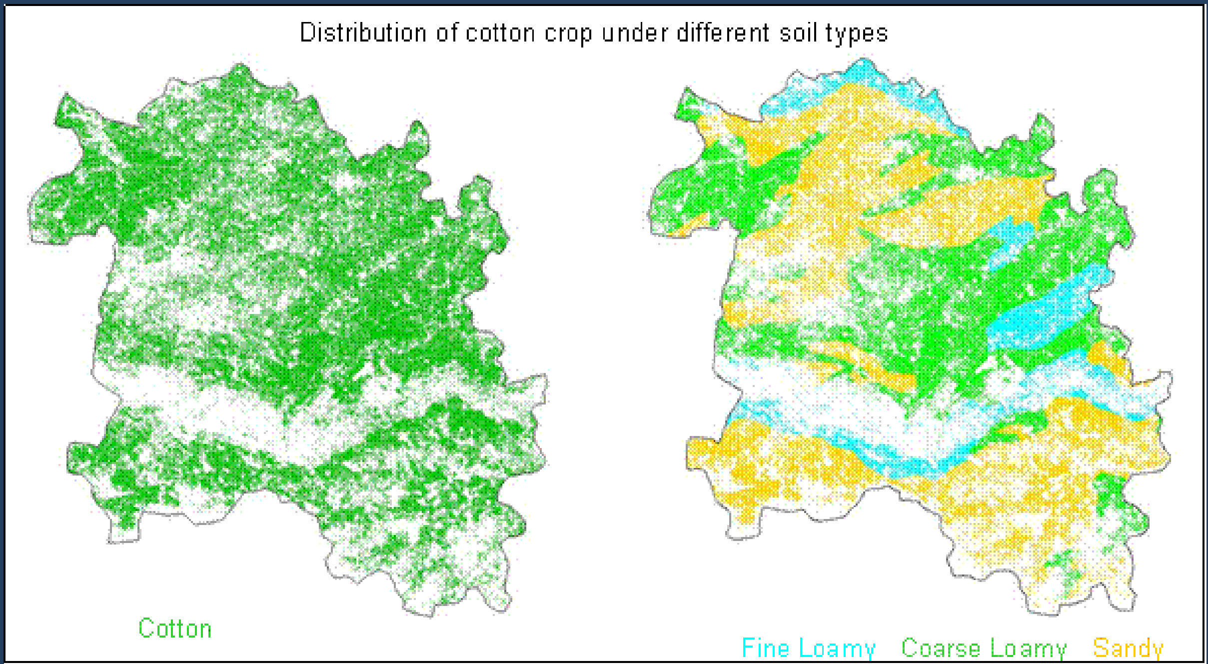


Fig 2: Cotton crop derived from LISS-III data and its distribution under different soil types

Bharuch district:

The major crops of the district are cotton, sugarcane, banana, bajra and jowar. The bajra and jowar crops were harvested during November months and long duration crops viz., cotton, sugarcane, banana were standing in the field during December and January months. It was observed during field visits that the hybrid varieties of cotton were well established covering the soil background in December. The desi varieties of cotton were grown with higher spacing of 5 X 5 ft and thus, the soil was exposed .

Due large variations in cotton cultivation practices in the district, two dates LISS-III data of December 30, 2006 and January 04, 2007 were utilized for deriving distribution of cotton crop and given in Fig 3. The figure indicates that cotton crop having good growth manifested in bright red colour on satellite data and the crop with large spacing manifested as dull red to cyan colour due to soil and crop mixture especially in the western parts of the district. The separability of cotton crop was better during December month data as the crop growth and spread was better. However, the poor cotton distributed in the western part of the district could not be discriminated due exposure of soil and poor crop growth.

The spatial distribution of cotton crop in Bharuch district along with its distribution in different soil types and depth is depicted Fig 4. The figure indicates that the cotton crop was distributed throughout the district and area is more concentrated in the northern part of the district.

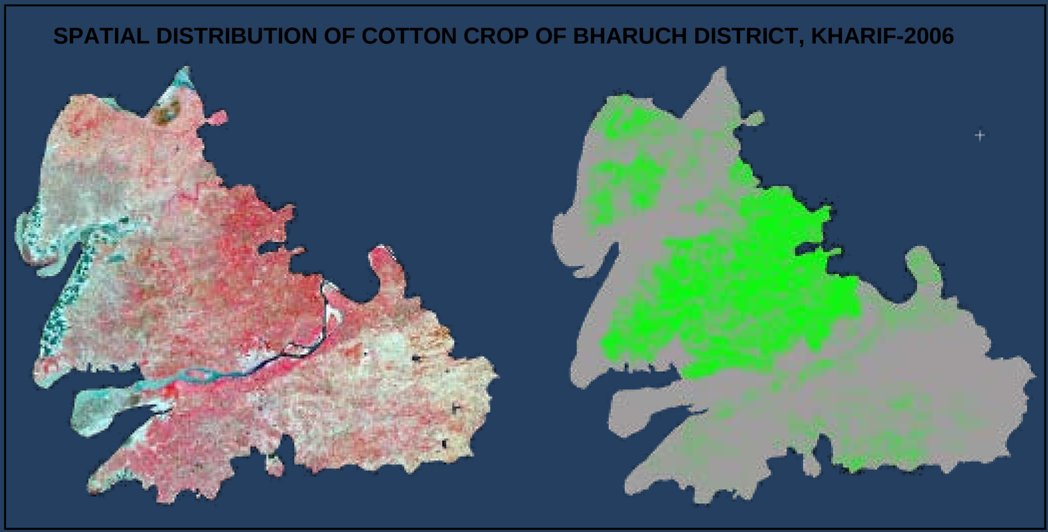


Fig 3: IRS LISS-III data of Bharuch district, Gujarat

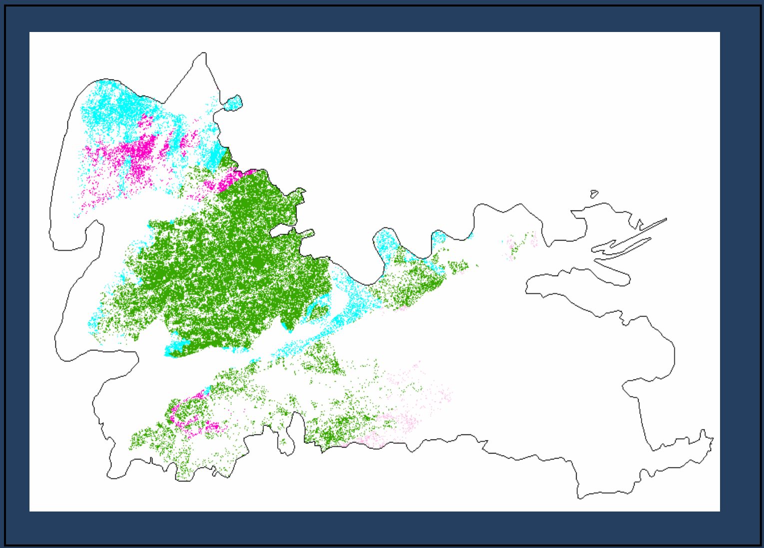


Fig 4: Cotton crop derived from LISS-III data and its distribution under different soils

The satellite data analysis for Bharuch district showed about 1.31 lakh ha area under cotton cultivation during 2006 season. The GIS analysis of crop and soils showed that about 77.7 per cent of total cotton cropped area is cultivated in very deep clayey soils and 13.6 per cent of cotton is cultivated in deep loamy soils. About 92 per cent of cotton crop was cultivated in deep soils indicating that the cotton crop in Bharuch district is cultivated under highly suitable soils. Only about 1.2 per cent of cotton crop was cultivated in shallow clayey soils.

Nagpur district

Cotton, rice and jowar are the important crops of the study area. The cotton crop cultivated as monocrop as well as intercropped with redgram. Citrus is one of major horticultural crops of the district. Two date LISS-III data of October month was used for deriving cotton crop. The raw data of LISS-III covering Nagpur district alongwith classified data is depicted in Fig 5.

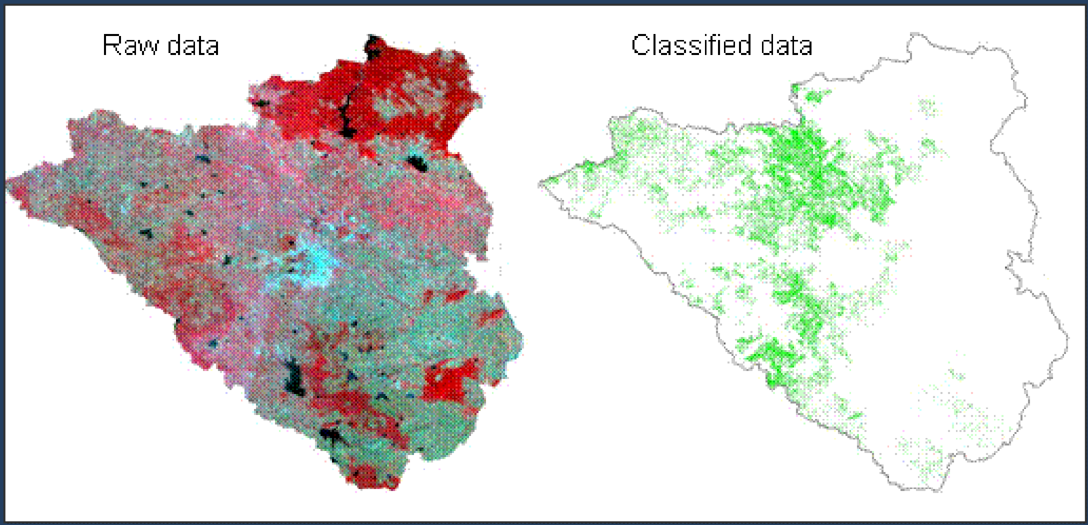
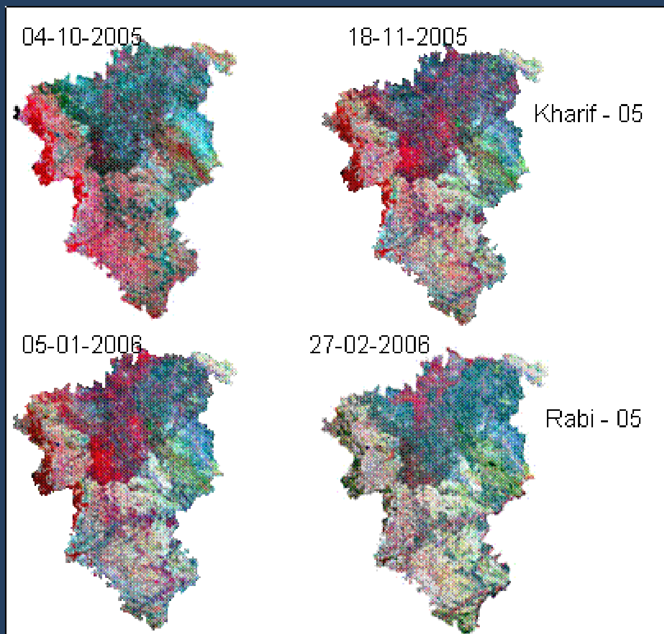


Fig 5: IRS LISS-III raw and classified data of Nagpur district, Maharashtra

Total cotton crop acreage estimated thorough remote sensing data was 68999 ha. The satellite derived cotton crop was integrated with soil and weather data for generating proportion of cotton crop under different pedo-climatic regimes. The distribution of cotton crop in all the nine polythesian triangles corresponding to each of meteorological stations along with the soil information was carried out for the district. Cotton crop is distributed in different soil depths ranging from very deep to shallow soils. It was also observed that the crop is cultivated in different soil types ranging from fine loamy, coarse loamy and clayey soils.

Dharwad district

Dharwad district represents the southern cotton production zone where the cotton crop cultivation is practiced in both kharif and rabi season. Hybrid varieties are cultivated in the kharif season and the desi varieties are cultivated in the rabi season. Multi-date AWiFS data from October to February months were analysed for discrimination of kharif and rabi cotton in the district due to wide variations in cotton sowing periods. The multi-date data corresponding to kharif and rabi season is given in Fig 5. October and November month data was utilized for discrimination of kharif cotton while December, January and February month data was used for delineation of rabi cotton. The figure indicates that the kharif cotton is clearly manifested on November month data as most of other crops were harvested. In January month data both cotton and wheat was manifested in similar tones of redness, however addition of February data enabled delineation of wheat crop which helped in cotton crop acreage estimation. Kharif cotton is cultivated thorough out the district while rabi cotton is mostly restricted to central parts of the district.



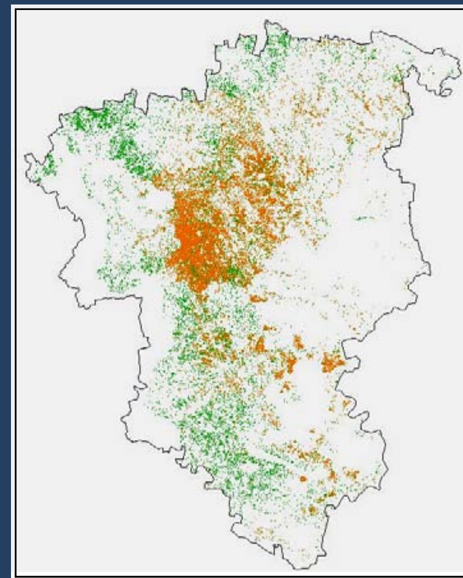


Fig 5: Spatial Distribution of kharif and rabi cotton in Dharwad district, Karnataka.

Both the kharif and rabi cotton crop was combined to derive total cotton cropped area in the district and the total cotton area in the district estimated to be 1.79 lakh ha. Cotton crop is distributed across all soil types and depths.

Validation of yield prediction by the integrated approach

In order to validate the data predicted by the integrated approach at different soil types, seed cotton yield from 29 farmers field belonging to different soil categories viz. shallow, medium and deep were collected and compared with the satellite derived data. It is clear that except one point for all the other soil types the model prediction was reasonably well with an r^2=0.52.

Production estimates derived through Integrated approach

The integrated methodology developed under this project (utilizing crop model, GIS and RS data basis) for district level assessment of production and productivity performed reasonably well in respect of three districts viz. Dharwad, Bharuch and Surat, while for Nagpur district the estimates were slightly on the higher side.

Crop production and productivity estimates by the integrated approach across the districts

District	Estimate by integrated approach	
	Productivity (kg/ha)	Production (000 bales)
Nagpur	**1543**	**713**
Sirsa	**2145**	**672**
Dharwad	**985**	**1040**
Bharuch	**1564**	**1274**