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FASAL concept in meeting the requirements of assessment and forecasting crop production affected by extreme weather events

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सार – भारत में बहुत पहले वर्ष 1969 मे पहली बार कृषि क्षेत्र में दूरसंवेदी अनुप्रयोग में अनुसंधान कार्य आरंभ किया गया। उपग्रह संवेदकों, डेटा संसाधन एल्गोरिथ्म्स, मॉडलों और समय के अनुसार संगणक शक्तियों में विकास के साथ यह अनुसंधान कार्य स्टेकहोल्डर्स को कटाई के पूर्व फसल उत्पादन का पूर्वानुमान देने का महत्वपूर्ण प्रचालनात्मक कार्य करते हुए केप (सी ए पी ई) और फसल (एफ ए एस ए एल) की प्रचालनात्मक परियोजनाओं के विकास के रूप में अपने चरम पर पहुच गया है। फसल उत्पादन का पूर्वानुमान देने के लिए दूरसंवेदी डेटा के आनुक्रमिक विकास का ब्यौरा इस समीक्षा पत्र में दिया गया है। इस शोध पत्र में भारत में फसल की पहचान और उपज का आकलन करने के लिए एकल और बहु-कालिक ऑप्टिकल तथा माइक्रोवेव उपग्रह चित्रों का उपयोग करके वैज्ञानिक विकास की समीक्षा की गई है। इसमें मौसम की चरम परिघटनाओं के अंतर्गत फसल का मूल्यांकन करने के लिए दूरसंवेदी डेटा का उपयोग करके भी कुछ परिस्थितियों के अध्ययन प्रस्तुत किए गए हैं। इसमें बाढ़, सूखा तथा ओला तूफान की चरम मौसमी परिघटनाओं के कारण फसलों के नुकसान का मूल्याकंन भी शामिल है। हानिकारक कीटों और बिमारियों के कारण फसलों के नुकसान का मूल्यांकन करने में दूरसंवेदी के उपयोग के उदाहरण लिए गए हैं और उपग्रह से प्राप्त किए गए मौसम प्राचलों का उपयोग करके उन घटनाओं के पूर्वानुमान की समीक्षा की गई है।

ABSTRACT. The research in remote sensing application in India started first in agriculture way back in 1969. With the improvement in satellite sensors, data processing algorithms, models and computational power over time, this research culminated into development of operational projects of CAPE and FASAL, tackling an important issue of operationally providing pre-harvest crop production forecast to stakeholders. This review paper details the sequential developments in the use of remote sensing data for crop production forecasting. The scientific developments in the use of single and multi-temporal optical and microwave satellite images for crop identification and yield estimation in India have been reviewed. The case studies on use of remote sensing data for crop assessment under extreme weather events are also presented. These include the assessment of crop damage due to extreme weather events of floods, drought, and hailstorm. Examples on use of remote sensing for crop damage assessment due to pest and diseases and forecasting their incidence using satellite derived weather parameters are reviewed.

Key words – FASAL, Damage crop, Extreme weather.

1. Introduction

India has a vast geographical area of 329 Million ha, of which 142 Million ha is under agriculture. Only 37 per cent of the agricultural area is under irrigation, leaving major part of agricultural area totally dependent on weather. Country receives 420 mhm (million hectare meter) of annual precipitation; with wide variability in its distribution has resulted in country having large diversity in agro-climatic conditions. Accordingly country is divided in to 15 agro-climatic zones. The diversity in agro-climatic condition provides suitable environment for growing about 215 crops in the country. The large variability in the distribution of precipitation often leads to floods and droughts in some part of the country, almost every year. The diverse crop growing conditions coupled with uncertainties in weather pose problem of managing agriculture as a resource. In view of these, country needs accurate and timely information on the crop prospects on a regular basis at different spatial scales. Indian space programme since its inception has been oriented towards providing solution to actual problems in the country. Accordingly, the remote sensing activities in the country began with focus on agriculture by conducting the very first experiment on coconut root-wilt disease study (Dakshinamurthy *et al*., 1971). The agricultural remote sensing has reached high level of maturity with time in various domains. Consistent efforts have been made in development of applications for assessment and forecasting of crop production, technique and software development to facilitate their easy adoption by large set of users and institutionalisation at user end. Crop assessment under extreme weather events has been addressed. Developments which have taken place in this field in the country are described in the paper.

2. Crop production forecasting using remote sensing data

Remote sensing applications for crop assessment and forecasting has been the area of focus world over. Laboratory for Applications of Remote Sensing (LARS) was established in 1966 in Purdue University to follow the multi-disciplinary approach of using the space technology for observing and managing agricultural resources (Landgrebe, 1986). Work began with conducting the spectral signature studies, use of aerial photographs and developing the techniques for machine processing of remote sensing data. Indian remote sensing programme too began almost with similar approach. While the first experiment on use of multi-spectral remote sensing using colour infra red (CIR) aerial images was on detecting the diseased coconut in parts of Kerala (Dakshinamurthy *et al*., 1971), subsequent studies addressed the use of CIR and multi-band aerial photographs acquired from aircraft and balloon platforms to identify different land covers, crops, and crop disease (Sahai and Barde, 1976; Dhanju *et al*., 1978; Sahai and Venkatesh, 1978). Machine processing of remote sensing data for crop classification was also addressed by Sahai and Venkatesh (1978).

Satellite remote sensing for crop production forecasting has been a major area of attention world over. Global and regional scale crop assessment was addressed under two major programmes; Large Area Crop Inventory Experiment (LACIE) of USA and Monitoring Agriculture through Remote Sensing (MARS) programme of European Commission (EC). The LACIE project was undertaken jointly by NASA, NOAA and USDA (MacDonald *et al*., 1975). It aimed at making use of Landsat MSS data for wheat crop area estimation and NOAA data derived weather parameters to forecast the crop yield. Major wheat growing areas of the world were covered using a sample segment approach and digital analysis of temporal data. MARS project of EC covered countries in Europe and followed the combined use of remote sensing data for crop assessment and weather data (both in-situ and satellite data derived) to address the crop condition and yield components (Sharman, 1993). MARS programme began by covering five pilot target areas each about 20,000 km^2 for estimating the acreage of major crops grown in the region (Gallego, 1999). Now, MARS project covers, not only the countries under European Commission, but also other major food grains producing countries in the world. Satellite data is used to make periodic assessment of crop prospects and monthly bulletins are issued by the Monitoring Agricultural ResourceS (MARS) Mission Unit (www.mars.jrc.ec.europa.eu).

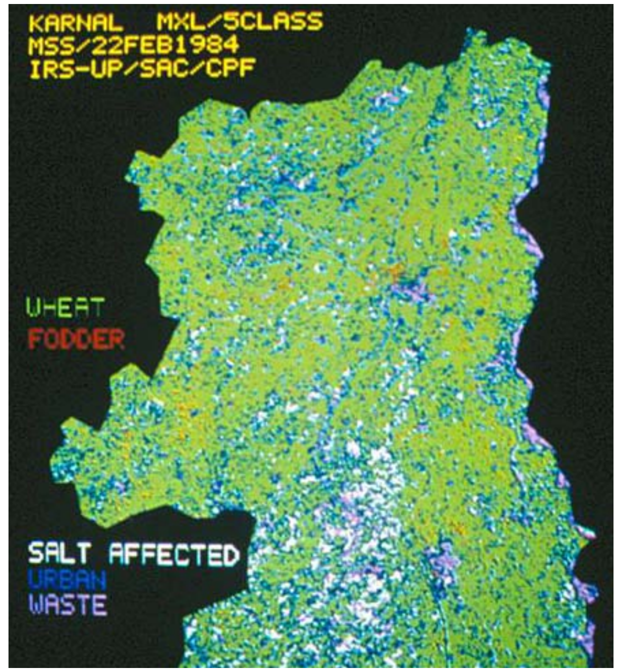

Fig. 1. Wheat crop acreage estimation for Karnal District, Haryana, using satellite digital remote sensing data (Dadhwal and Parihar, 1985)

The Indian efforts on satellite remote sensing for crop production forecasting began under the Indian Remote Sensing Satellite Utilization Programme (IRS-UP). Studies such as Crop Production Forecasting (CPF), Crop Stress Detection (CSD) and Crop Yield Modelling were initiated in 1980's (Anon., 1982). Using the Landsat MSS digital data, feasibility of crop identification was demonstrated by estimating wheat cropped area in Karnal district of Haryana (Fig. 1) (Dadhwal and Parihar, 1985). Wheat acreage estimate was made by using the ground truth information for digital classification of Landsat MSS data acquired in the month of February. Supervised digital classification of the image was based on Maximum Likelihood classifier (Fu, 1983). The success led to development of the Large Area Crop Acreage (LACA) Estimation project under the Remote Sensing Application Missions of Deptt. of Space, Govt. of India in 1986 (Anon., 1988). It was followed by Crop Acreage and Production Estimation (CAPE) project developed at the behest of Department of Agriculture and Cooperation (DAC), Ministry of Agriculture, Govt. of India.

CAPE project was based on the use of multi-spectral data acquired at peak vegetative stage of crop and

Maximum Likelihood (MXL) classification of sampled remote sensing data, following stratified random sampling approach. Crops like wheat, rice, groundnut, sugarcane and rapeseed/mustard were covered. It involved development of procedure for selection of project area, sampling approach for different crops, ground truth site selection and digital classification techniques to support the crop production forecasting. Procedure were developed and tested for making state level production forecast of wheat (Dadhwal *et al.*, 1991) and rice (Panigrahy *et al.*, 1991) crops. Semi-automated software CAPEMAN, was developed for digital image analysis (Anon., 1995). The menu-driven s/w package facilitated step-by-step image analysis for crop acreage estimation, guiding an analyst to subsequent step once current step has been successfully completed. The user friendly s/w enabled participation of multi-institutional team in the digital image analysis. CAPE project established the use of remote sensing for crop production forecasting, its success led to a demand for multiple in-season forecast of many crops by DAC. This included making crop forecast from the field preparation stage itself to in-between assessment till crop is harvested and need for national level forecasts. Schedule for acreage estimation and production forecasts, respectively, as suggested by DAC are given below:

(*i*) *Kharif-rice* : J&K, Punjab, NE Hill States-June end and mid September; Haryana, UP, Southern states-mid July and September end; Assam, Bihar, MP, Orissa, West Bengal & other states/ areas-July end and mid October. All India- July end and mid October; Revised all India acreage estimate by August end and production forecast by October end.

(*ii*) *Wheat* : Gujarat, Maharashtra, MP and Rajasthan-December end and February end; other states-January end and March end; All India-January end and March end; Revised all India-acreage estimate and production forecast - January 31 and March 31.

2.1. *Crop production forecasting with multi-source data*

In order to meet the requirement of multiple in-season forecasts of crops, the option of using various technologies, *viz.*, Econometric, weather based forecasting and remote sensing data based assessment and forecasting, were examined. There are three crop seasons in the country, *viz.*, *Kharif*, Rabi and summer (Zaid). Sowing/planting of a crop across the country is distributed over months. The *Kharif* crop sowing/planting is controlled by onset and amount of rains in majority of the partially irrigated and rainfed regions of the country. Sowing is mostly done once enough soil moisture is

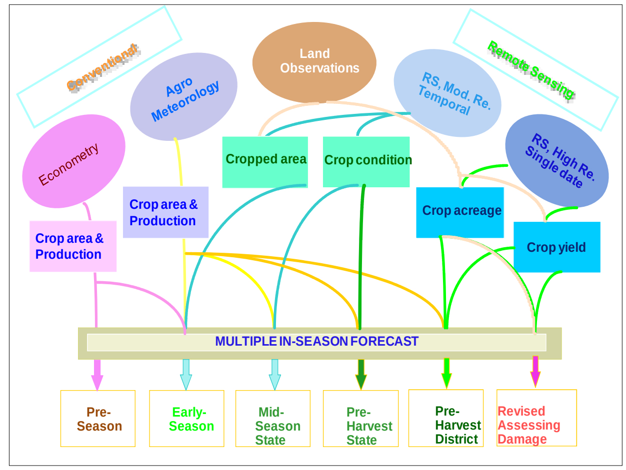

Fig. 2. The concept of using multi-source data for making multiple in-season assessment of crop

available for seed germination. In case of wetland rice, field preparation requires accumulation of adequate water for puddling the rice paddies. Normal date of onset of monsoon on Indian landmass ranges from 1st of June to 15th of July from southern tip to north-western region, respectively (Rao, 1976). Accordingly, schedule for field preparation, sowing/planting have a large range across the country. Spectral emergence of crops for optical remote sensing data is 30-45 days after sowing. Crop detection in remote sensing data becomes possible, when the data is acquired about 45 days after the crop sowing. In order to meet the information need of DAC on crop prospects right from the field preparation stage, use of multi-source information like weather, econometric and field survey was visualised, while formulating the FASAL-Forecasting Agricultural output using Space, Agrometeorology and Land based observations, concept (Parihar and Oza, 2006). The FASAL system integrates various approaches for creating hierarchical information related to crop acreage, crop condition and crop production at any time of the crop life cycle (Fig. 2).

Early in the crop season use of econometric and weather-based models was envisaged for forecasting the total expected cropped area, before the crop becomes discernible with remote sensing data. Mid-season assessment is made with coarse spatial resolution but high temporal remote sensing data. In the latter half of crop growth, remote sensing data is used to estimate the crop acreage and forecast the yield by integrating remote sensing and meteorological data. In addition, the use of field information and weather data at various stages were expected to make the forecasting system robust and achieve the goal. A generalized methodology flowchart of

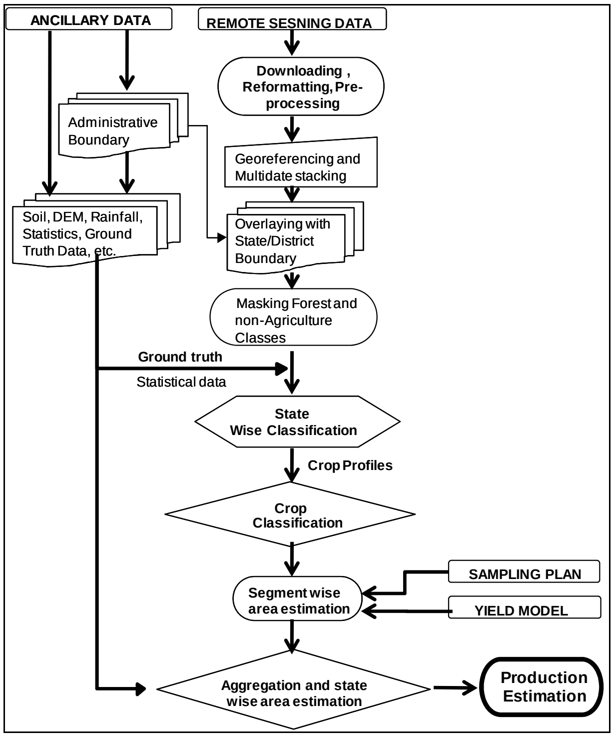

Fig. 3. Block diagram of temporal remote sensing data based in-season crop assessment procedure

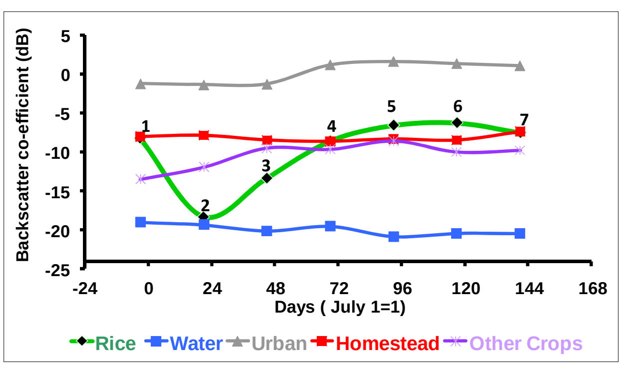

Fig. 4. Typical response of different land covers as observed in C-band SAR data

crop production estimation using remote sensing data is given in Fig. 3.

FASAL project was launched in 2007-08, starting with *Kharif*-rice in Odisha state to develop and test the procedure for multiple in-season forecasting. Procedure development, testing and implementation was achieved for making assessment of six crops, *viz*., wheat, *Kharif*-rice, Rabi-rice, Winter-potato, rapeseed/mustard and jute, covering major growing regions in the country. FASAL technique development and implementation was shared among partner institutions with particular domain expertise. Accordingly SAC was responsible for remote sensing, India Meteorological Department for agro-meteorology and Institute of Economic Growth for econometric component. A large team drawn from State Remote Sensing Applications Centres, State Agricultural Universities, Indian Council of Agricultural Research Institutes as well as institutions like Institute for Wetland Management and Ecological Design West Bengal. Major emphasis of FASAL being on remote sensing, details of techniques based on different type of remote sensing data are described in the following section:

2.1.1. *Crop production forecasting with temporal optical remote sensing data*

Temporal evolution of spectral signatures of land covers is used in the analysis of multi-date remote sensing data (Oza *et al*., 2002). Remote sensing data from Wide Field Sensor (WiFS) and Advanced Wide Field Sensor (AWiFS) onboard Indian Remote Sensing Satellites (Joseph *et al*., 1996) has been the source of multi-spectral data. The datasets are prepared by, first registering the individual acquisition images on a master image. In the second stage vegetation index is generated using the Red and Near-Infra Red band images. The sample segments are classified using in-season ground truth and a hierarchical (decision rule based) classifier. The acreage estimates are aggregated at state and national level, thus estimates are available at state and national levels. The production forecast are generated by using the multiple regression models based on weather data using a correlation weighted regression approach. The National level acreage and yield estimates are then combined to provide national production forecast (Oza *et al*., 2002).

2.1.2. *Crop production forecasting with temporal synthetic aperture radar data*

During the monsoon season, persistent cloud cover limits the availability of optical remote sensing data. To overcome this problem, use of Synthetic Aperture Radar (SAR) data is an option. Such data from Indian RADAR imaging Satellite (RiSAT-1) satellite is available now (Misra *et al*., 2013). Initially data from Radarsat-1 and 2 were explored and used (Rany *et al*., 1991; www.asc-csa.gc.ca/eng/satellites/default-eo.asp). Temporal C band SAR data has been found to be useful in identification of wetland rice and jute crops (Panigrahy *et al*., 1999; Chakraborty *et al*., 2005). The procedure developed and used is based on the use of backscattering properties of different land covers as observed in SAR data (Fig. 4).

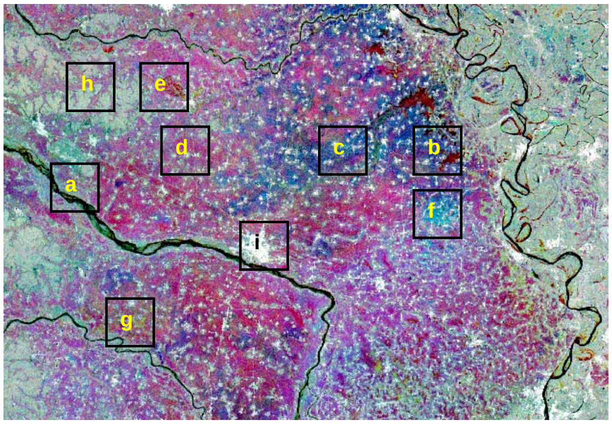

Fig. 5. Three-date color composite of Radarsat Scan SAR data (R:G:B: Date-1:Date-2: Date-3) showing signature of rice (b, c, d, e, f) in different growth stages and other land cover classes (a: water, h: forest and i: urban)

In this procedure temporal SAR data is first registered over a master image, decision rule for classification are developed using the temporal evolution of signature for different land covers. Wetland rice crop at different growth stages shows distinct signature in multi-data SAR data (Fig. 5). The statistical relationship between yield and rainfall during the cropping season is used for yield forecasts. This procedure became operational in 1998 and it has been regularly used for *Kharif*-rice crop in India.

2.1.3. *Crop production forecasting with single date optical remote sensing data*

Crop acreage estimation, basically involves identifying the typical spectral signature of a crop in the remote sensing data and then estimating the number of pixels with nearly similar spectral signature. Crop acreage estimation using the remote sensing data, is being carried out on operational basis using two approaches for remote sensing data extraction, *viz.*, boundary mask and sample segment approach. In case of boundary mask approach, a mask of administrative unit under consideration is overlaid and pixels inside the area are analysed (Dadhwal and Parihar, 1985). While, in sample segment approach a grid of uniform size is used and fraction of segment are drawn from remote sensing data and analysed. Accordingly procedure for district level wheat production forecasting (Dadhwal *et al*., 1991) and rice production forecasting (Panigrahy *et al*., 1991) have been developed and used. In case of boundary mask approach, whole image of the study area is analyzed, while in sample segment method only the selected sample segments are analyzed. In the sample segment method, the samples are selected employing two methods; Simple Random Sampling and Stratified Random Sampling (Cochran, 1963). In simple random sampling approach, segment population is considered to be homogenous. While in stratified random sampling, population is treated as in-homogenous, hence it is divided in uniform strata. The stratification is done, accounting for the agricultural/ nonagricultural fraction and/or agro-physical condition of agricultural area. Maximum Likelihood (MXL) supervised classification algorithm is used for image analysis to derive crop acreage estimates (Fu, 1983).

2.1.4. *Crop yield forecasting*

Crop yield forecasting is an important component of crop production forecasting. Weather and remote sensing data, both have been used for crop yield forecasting. Assessment of expected crop yield using crop growth simulation models, to capture the yield at a given stage has emerged useful. Spectral data based indices also have been used to run the crop growth simulation models like INFOCROP and WOFOST. Remote sensing data based derived parameters like, sowing date, Leaf Area Index (LAI) and NDVI are used along with weather data in the WOFOST model to predict the crop yield at a given crop stage (Chaudhari *et al*., 2010; Tripathy *et al*., 2012). Remote sensing data has been found useful in capturing the crop phenology, which intern is used in the crop growth simulation models (Sehgal *et al*., 2002). Vegetation index derived from remote sensing data have been used independently as well as along with weather data to forecast the crop yields. Empirical relationship between the vegetation indices like LAI, NDVI at a given crop stage and crop yield have been developed and used. Such models have been found useful when in-situ weather observations are also used along with remote sensing based indices (Dadhwal *et al*., 2003). Such models have been developed for wheat, cotton (Ray *et al*., 1999), rapeseed/mustard crops (Potdar *et al*., 1999). Empirical relationship between vegetation indices derived from IRS-LISS-I data and rice yield were found useful for rice production forecasting in Odisha state (Ravi, *et al*., 1992) and wheat yield in Punjab state (Dubey *et al*., 1994). Growth profile based approach using temporal, coarse spatial resolution, multi-spectral MODIS data has been reported for its potential in assessing the regional scale wheat yields (Oza *et al*., 2010).

Surface weather observations available primarily from India Meteorological Department (IMD) and in some cases from Agricultural Universities were used for crop yield modelling. Historical weather data were used to develop the relationship with weather parameters and crop yields. In-season weather data was used for making yield forecast. Such models have been developed and used for

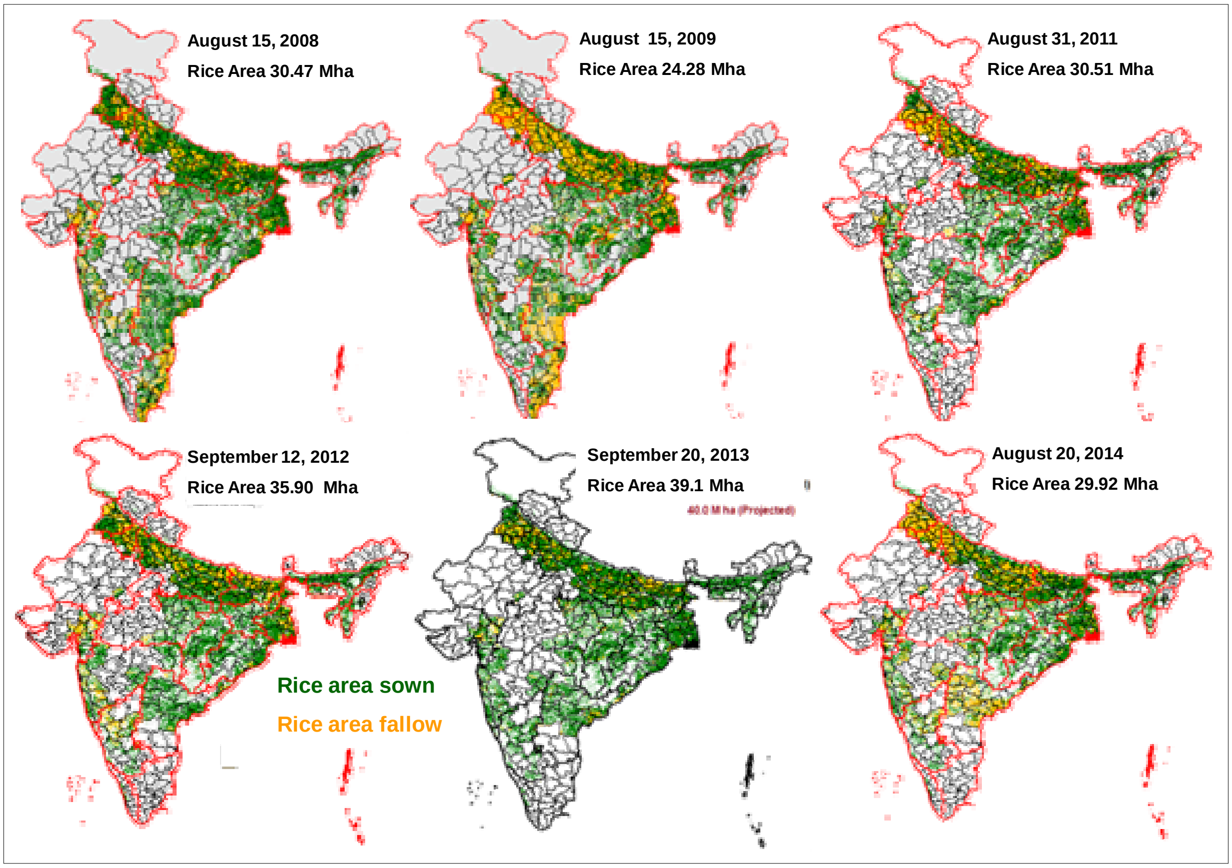

Fig. 6. *Kharif* rice area sowing prospects based on Available Soil Moisture (ASM) 2014 through 2008. *Kharif* Rice Area Sown as on August 31, 2011 was 30.51 (Mha) which was 7.3% lower compared to 2010. In 2014 the *Kharif* area was 29.92 Mha which was lower by 15.6% compared to average of last five years

forecasting the yield of crops like, wheat, *Kharif*-rice, Rabi-sorghum, rapeseed/mustard, potato, sugarcane, jute and cotton. Detailed account of such work is given in Chaudhari *et al.* (2010) and crop specific model development; wheat (Vyas *et al*., 1999), Rice (Dutta *et al*., 2001), groundnut (Dutta and Patel, 2004). Weather based models are based on *in situ* weather observations; rainfall and temperature have been found useful in explaining the yield variability in most of the cases.

2.1.5. *Early-season kharif crop prospect assessment with satellite based weather data*

The technique of early assessment of crop prospects based on soil moisture modelling using satellite data derived daily spatial rainfall has been developed. The procedure is based on the assumption that, soil acts like a bucket, so, initially whatever rain falls it keeps accumulating, beyond a threshold, it can store no more water, hence water will accumulate over the surface or it will flow away as runoff. The model uses the information on soil, slope and rainfall to assess adequacy of rainfall to support the crop germination, growth and survival (Chakraborty and Panigrahy, 2012). The irrigated area mask is used to separate out such areas. Accordingly, scenario for wetland rice and other crops are generated considering the fact that wetland rice requires saturated field condition to standing water, whereas, other crops grow in less moist conditions. Results from this approach are shown in Fig. 6. It is evident that crop growing conditions in normal monsoon years as well as abnormal year are well captured by this approach.

2.2. *Crop assessment in case of extreme weather events*

2.2.1. *Assessment of flood affected crops*

Examples of Cyclone generated sea surge inundating the cropped lands and/or heavy rains resulting in flooding the cropped lands are available. Two major event of this nature in India were (*i*) Super cyclone in October 29-30, 1999 (Patel *et al*., 2004) and (*ii*) Phailin cyclone in October 2013 (Chakraborty *et al*., 2014).

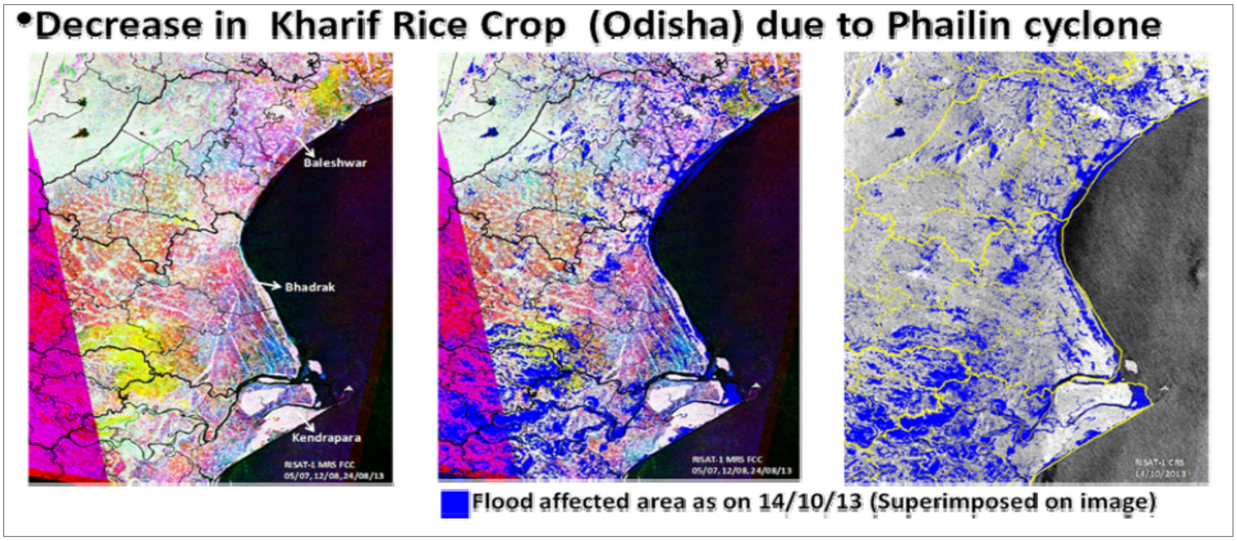

Fig. 7. Temporal RISAT SAR images showing the flood affected rice cropped area and cropped area in coastal Odisha before the Phailin cyclone of October 2013 and flooded area overlaid after the cyclone

Earliest available satellite data is preferred in such events. Normally cyclones are associated with cloudiness over the area; in such situation SAR data has been found to be useful during and immediately after the cyclones. RiSAT-1 SAR data acquired on October 14, 2013 was used to capture the rice cropped areas inundated due to Phailin cyclone in Odisha state (Fig. 7). As early as 1999 in the event of Super-Cyclone of October 29-30, 1999, Radarsat data acquired on November 2 and 4, 1999 was used. SAR data enabled mapping of the inundated areas as well as inundated rice cropped areas. It was followed by use of optical remote sensing data to derive the vegetation index and classify the extent of damage to rice crop (Patel *et al*., 2004). Agricultural area and cropped area mask are created from the satellite data acquired before the event. The temporal remote sensing data acquired after the event is classified to demarcate the flooded area at initial stage, and later to identify the damaged crop area. SAR and optical data both have been found to be useful in such extreme weather event. It was possible to generate information on inundated rice cropped area within a day after acquisition of SAR data by using the online transfer of SAR data over internet.

2.2.2. *Mapping of drought affected crop*

Temporal remote sensing data, acquired within the crop season is used to track the crop growth pattern. In the event of drought resulting in changes from normal crop season, multi-spectral remote sensing images show the difference very clearly (Fig. 8).

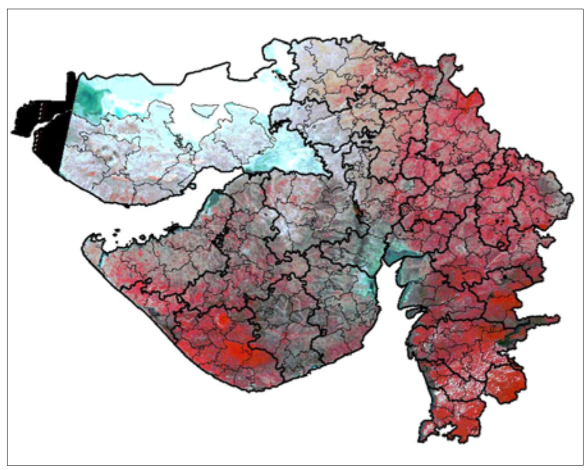

Fig. 8. Vegetation condition assessment (1998, 2000) in Saurashtra Region, Gujarat IRS-1D WiFS sensor data (Difference in red tone indicates difference between vegetation types and condition)

A large number of remote sensing data based vegetation indices have been developed for such applications. Most simple approach is to use Red and Near Infrared bands of remote sensing data to generate Normalised Difference Vegetation Index (NDVI). The growth profile of a season is compared with the growth of crop for a known normal year. A lower growth trajectory of NDVI supported with rainfall data is used to mark the drought affected crop area. Example of such an application for assessment of drought at national level is a

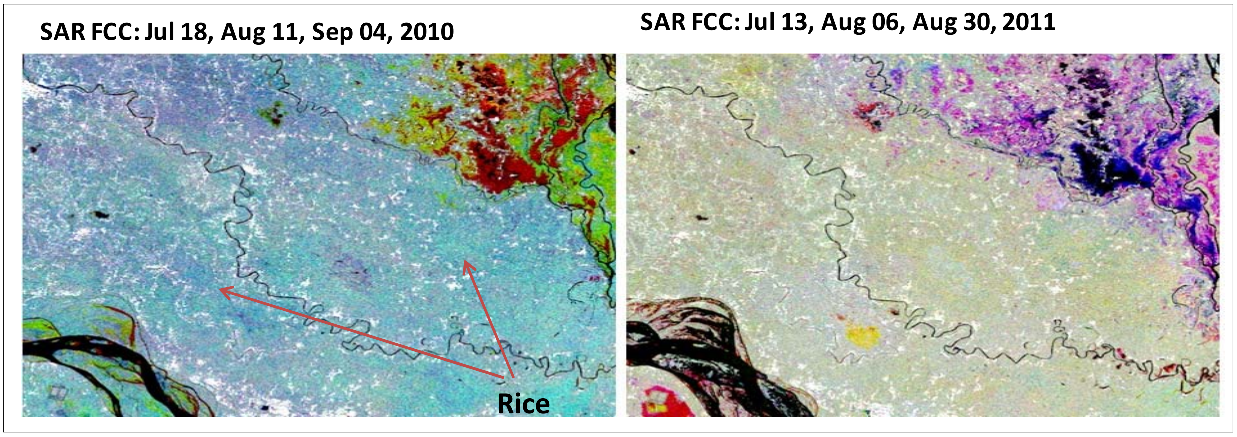

Fig. 9. Multidate SAR data showing decrease in Kharif rice crop (Begusarai, Samastipur, Bihar) in 2011 in comparison to 2012

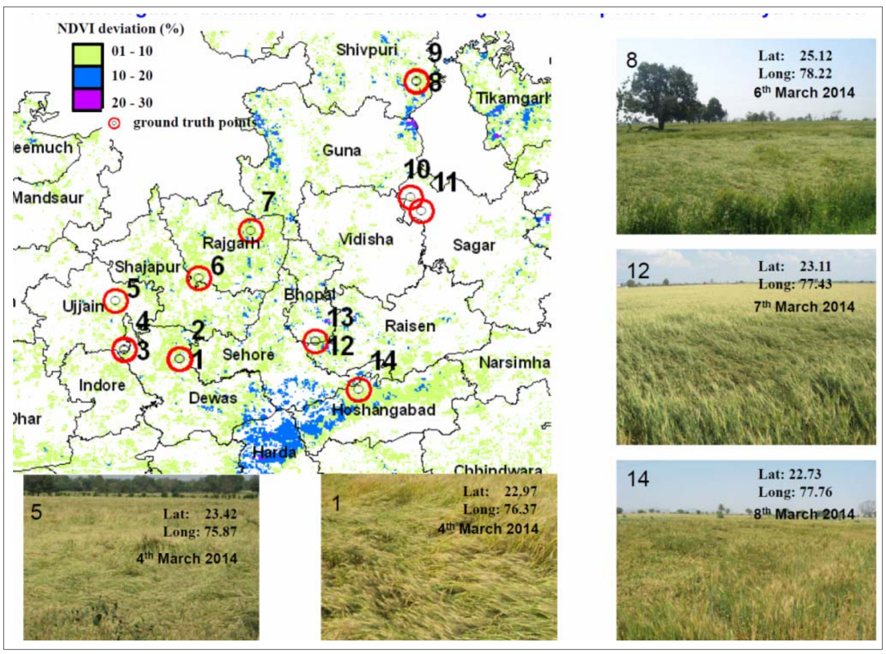

Fig. 10. Hailstorm damage as inferred from NDVI variation and field photographs showing affected crop field in parts of Madhya Pradesh state

project entitled National Agricultural Draught Assessment and Monitoring System (NADAMS). NADAMS is based on coarse to moderate spatial resolution, high temporal resolution data like NOAA-AVHRR, MODIS, WiFS and AWiFS. Time series of vegetation index images are generated in-season and used. However, during the Kharif season persistent cloud covers may limit the use of optical remote sensing data. To overcome such a situation SAR data has been found useful by tracking the pattern of SAR backscatter of cropped area. A comparison of profile of backscattering for current season with known pattern of profile during normal growth year gives an indication of drought. Image showing drought affected rice crop area is given in Fig. 9.

2.2.3. *Hailstorm damaged crop assessment*

Any thunderstorm which produces hail that reaches the ground is known as a hailstorm. This phenomenon is common during Rabi season. The hailstorm causes both mechanical and physiological damage to the crop. The damage is more sever if it coincides with latter part of crop season and near crop maturity. An example of the hailstorm over Madhya Pradesh and Rajasthan in last week of February 2014 and in Maharashtra in first week of March 2014 is given. NDVI images generated from the AWiFS data of Resourcesat-2 indicated negative deviation of 10 to 30% in NDVI from mean NDVI of last four years over parts of Madhya Pradesh and Rajasthan (Fig. 10).

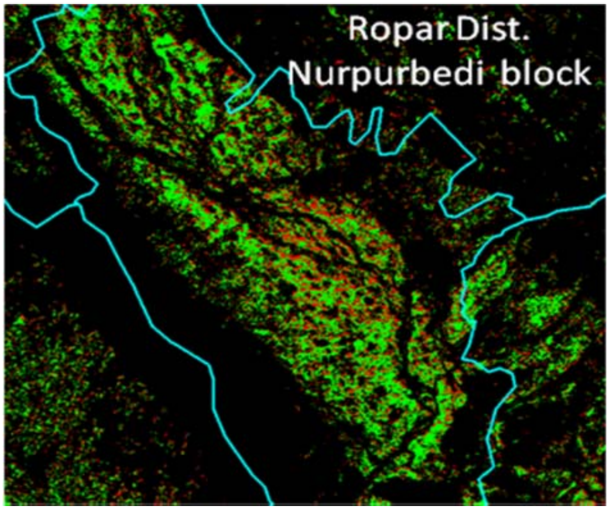

Fig. 11. Remote sensing images showing wheat rust affected areas in parts of Punjab state. Red indicates rust affected areas and green unaffected wheat (Dutta *et al*., 2014a)

2.2.4. *Pests/diseases incidence forecast and damage assessment*

Plant diseases and pests adversely affect the agricultural crops resulting in significant yield losses. It is reported that at least 10% of global food production is lost due to plant diseases (Christou and Twyman, 2004; Strange and Scott, 2005). There have been two kind of applications of remote sensing for crop pest/disease; (*i*) Forecasting the possibility of incidence of pest/disease, and (*ii*) Assessment of damage caused due to pest/disease incidence.

2.2.4.1. *Advance warning of pest/disease*

Many of the pest and diseases are known to occur under typical weather conditions. Remote sensing data based weather and crop calendar have been used to forecast the possibility of pest/diseases. Earliest example is of forecasting the incidence of wheat rust in the country (Nagarajan and Singh, 1973). The temporal remote sensing data of TIROS weather satellite to track the northward movement of clouds from Palani hills in peninsular India towards north western wheat growing regions of the country was interpreted as potential for incidence of wheat rust. A recent study on possibility of forecasting the occurrence of yellow rust in wheat has been demonstrated by Dutta *et al.* (2014a).

(a) *Advance warning of yellow rust in wheat*

The minimum and maximum temperature and RH forecasted using Weather Research Forecast (WRF) model output at 3 day interval and at 5 km resolution were used as inputs. Assuming that the temperature and RH remained same for every grid of 5 × 5 sq km in plain land (neglecting the orographic effect), regional level spread of wheat rust disease was forecasted (Dutta *et al*., 2014a). Spectral profile of the wheat crop was generated using multi-date AWiFS data. Information on disease initiation and infestation levels was collected by field observations. NDVI and LSWI indices were used to specifically identify the foci of infestation within the 5 km grid. This approach showed the spatial variability of crop growing environment, like temperature and humidity levels, conducive for pest infection in wheat growing regions. An example of wheat rust affected area in parts of Punjab State is shown in Fig. 11.

(b) *Advance warning of aphid and rot in rapeseed/mustard*

Incidence of aphid infestation in rapeseed/mustard crop is common in India. Modelling regional level spatial distribution of aphid (*Lipaphis erysimi*) growth in mustard using satellite-based remote sensing data was attempted by Dutta *et al*. (2008). The study area comprised of three sites located in dominant mustard growing region of India, covering parts of Madhya Pradesh, Rajasthan and Uttar Pradesh states. Near-surface meteorological parameters derived from National Oceanic and Atmospheric Administration (NOAA) Television and Infra-Red Operational Satellites (TIROS) Operational Vertical Sounder (TOVS) data and field observations on disease infestation were used. A model based on TOVS-derived cumulative surface air temperature and minimum specific humidity (SpH) was developed to estimate the date of 'aphid onset' (first appearance), date of peak infestation and location of severity with respect to aphid population density. Estimated dates of peak aphid infestation and peak population showed a strong match with the observed data. The location of peak aphid population density was depicted in each spatial grid of 25 × 25 km^2 for parts of northwest India. Comparison of predicted dates of attaining peak aphid population with observations indicated a deviation of ±7 days. Regional level model was applied over a large part of mustard-growing region for varying dates of sowing, surface air temperature and specific humidity, showing the spatial distribution of aphid severity zones (population density) and predicted dates of severe aphid infestation (peak population) at each grid level in the region (Fig. 12).

2.2.4.2 *Pest/disease damage assessment*

Disease symptoms manifest in many ways, such as loss of green pigments and change in pigment composition (chlorosis) or damage of tissue as lesions

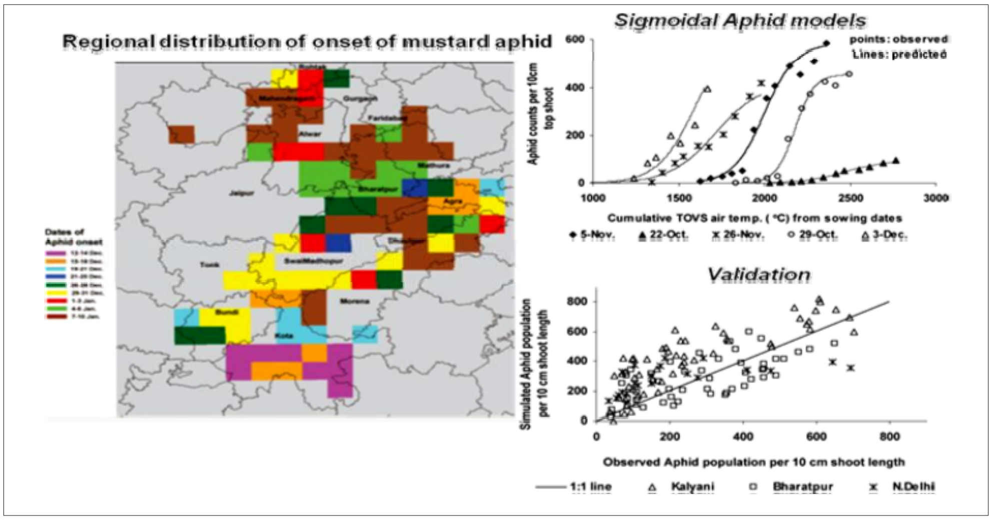

Fig. 12. Regional distribution of onset of mustard aphid (Dutta *et al*., 2008)

(narcosis), shriveling by dehydration/deformation of tissue (water content), or rise in tissue temperature. Depending upon the manifestation of disease symptom on the plant, spectral signature of diseased crop, differ from that of a healthy crop. This enables identification of stressed crop. Ancillary information is used to associate the remote sensing observations with severity levels. Attempts have been made to use the remote sensing data of different types; multi-band to hyperspectral; visible, NIR, SWIR and thermal bands.

(a) *Damage due to potato late blight*

Late blight incidence occurs under favourable temperature and humidity at particular crop growth stage. Shortwave infrared (SWIR) band is sensitive to vegetation cover and leaf moisture. In a study covering part of Bardhman district of West Bengal, high temporal and moderate spatial resolution MODIS was used for detecting potato late blight affected crop (Dutta *et al*., 2014b). Temporal Land Surface Water Index (LSWI) and NDVI indices have shown different patterns for healthy and diseased potato crops. LWSI profile has been found to be more sensitive in picking the changes in potato canopy. It was because the crop was irrigated and LSWI value of healthy crop increase gradually, while in stressed crop it decreased sharply.

3. Conclusions

The diverse crop growing conditions of India coupled with vagaries of monsoon make real-time monitoring of crop a challenging task. Improved weather forecasting coupled with remote sensing inputs has added advantage for crop monitoring with spatial details. Systematic efforts have been made to address the crop monitoring using a large variety of remote sensing data; optical and microwave, coarse and moderate spatial resolution, single date and temporal etc. The FASAL concept developed and validated has demonstrated successful application of geomatics in crop assessment and forecasting. Applications of remote sensing based crop assessment in the event of extreme weather condition have been developed and successfully used. It has been institutionalized as Mahalanobis National Crop Forecast Centre by Departmen of Agriculture & Cooperation, Govt. of India.

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Remote Sensing Centre, Regional Remote Sensing Centres, State Remote Sensing Centers, Agricultural Universities, India Meteorological Department, Central Potato Research Institute, Indian Agricultural Research Institute & many other Institutes of Indian Council of Agricultural Research, Institute Environmental Studies & Wetland Management, Kolkata and State Agricultural Departments made it possible to develop, validate and establish the EO methodology. Author is deeply indebted to all the above mentioned institutions their and staff who contributed in the projects.

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