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Optical remote sensing applications in crop mapping and acreage estimation: A review

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Abstract
Crop identification and mapping is pre-requisite for various crop planning and management activities. Crop type maps were generated by national and multinational agricultural agencies, insurance agencies, and regional agricultural boards to prepare an inventory of what was grown in certain areas and when. This serves the purpose of forecasting of grain supplies (yield prediction), collection of crop statistics, facilitating crop rotation records, mapping soil productivity, identification of factors influencing the crop stress, assessment of crop damage due to storms and drought, and monitoring the farming activities. Identification of crop types and delineating their extent to generate the reliable statistics play the key role in agriculture planning. Optical remote sensing makes use of visible, near infrared and short-wave infrared sensors to form images of the Earth's surface by detecting the solar radiation reflected in these wavelengths from targets on the ground. Different materials reflect and absorb energy differently at the visible and infrared wavelengths. Thus, targets can be differentiated by their spectral reflectance signatures captured in the remotely sensed images. The aim of present study was to review the application of optical remote sensing in crop mapping and acreage estimation. The review of the studies indicates that the optical remote sensing has equal capabilities in crop identification and acreage estimation with some of the limitations like, availability of cloud free images and spatial resolutions. However, advancement in spatial and temporal resolution optical remote sensing allowed accurate discrimination amongst the crop types and other vegetation.

Keywords: crop acreage estimation, irs, landsat, modis, optical remote sensing

Introduction

The timely and reliable information on crop sown area become most significant fraction in development of management strategies by the planners and administrators in the field of agriculture and allied sectors. The crop acreage statistics form a base for the numerous applications such as yield forecasting, managing the grain storage, procurement of price, making the strategies like import and export of commodities, requirement of fertilizers and pesticides, and settlement of crop insurance [1], release of development funds and compensation packages *etc*. It is proven by the various researchers worldwide that the remote sensing plays a great role in fast and timely analysis of crop acreage and production forecast on small to large scale of mapping due to easy availability of satellite data at different resolutions and area coverage with temporal facility [2,3,4]. Remote sensing-based crop acreage estimates found more accurate, reliable, time and cost saving and easy to exchange of information over the conventional methods. In conventional method of data collection, a local officer of the concerned department especially agriculture/revenue, use to collect the information about the crop sown, acreage, production and record/ maintained it in the register book. The process found to be a time consuming and least realistic some time due to unavailability of required instrumentation, inaccessible areas to be visited, chance of error during data entry, loss of records and data processing errors are involved. In conventional methods, for example statistics of food crops are based on land revenue system. In India, states like Kerala, Orissa and West Bengal, 20 percent sampling on rotation basis is used, north eastern states rely on adhoc surveys, while multi season full enumeration approach is adopted in the remaining part of the country. Acreage estimates from these surveys must pass through a hierarchy of aggregation of village, taluka, district and state level, which contributes to a delay in compilation of national forecasts [5, 6].

Advancements in remote sensing technology coupled with information technology has enhanced the capability of gathering enormous and realistic data as well as information, ranging from historical data, ground truth values and aerial photography to satellite data [7].

It reduced the field work to a considerable extent and features boundaries are more precisely delineated than in conventional methods. Hence, it is a highly proven technology that is effective for mapping and characterizing land resources including crops and different vegetation [8]. Remote sensing offers an efficient and reliable means of collecting the information required, in order to map crop type and acreage. Besides providing a synoptic view, remote sensing can provide structure information about the health of the vegetation. The spectral reflection of a field will vary with respect to changes in the phenology (growth), stage type, and crop health, and thus can be measured and monitored by multispectral sensors [9]. Satellite images and other related information can be further processed, managed, and analyzed with the help of Geographic Information System (GIS). The locational information can be collected from ground in the form of ground truth database with the help of Global Positioning System (GPS) tool that linked with satellite images in analysis process for cross checking and feature identification that results in better accuracy in crop identification, mapping and acreage estimation.

Conventional Methods of Crop Acreages Estimation and Its Limitations

Map Based Method: FAO, 1982

There are numbers of conventional methods used to estimate the cropped area. In India, when the cadastral maps are compiled, each parcel shows the owner and his holding information. The local revenue officer use to visit each farmer's field in a village and update the information like crops grown with covered area, whether irrigated or rainfed etc. in each parcel. This village information compiled then Block wise and then District wise and so on. This is one of the easy and accurate methods [10]. The main drawbacks of this method are it is time consuming; it cannot work at where the cadastral map is not available.

Land survey method

This method determines the forms and extent of cropped area on the earth surface by measurements [11, 12]. Method involves measuring the length of each side and the angle of each corner of the field using a measuring tape and a compass. The surface area of the plot can then be calculated using trigonometry. In this method, first the boundaries of a field to be measured are identified by use of sight poles and taking compass hearings and measuring the length of each side of the obtained polygon. The traditional procedure of evaluating the area of a field on the basis of measurements entails plotting the field in the office by using a ruler and a protractor and then measuring the area of the sketch by using a planimeter or grid paper. This method often provides accurate area measurements and can be used directly in the field when measurements are made, but it is time consuming and more difficult to apply on ground.

Farmer assessment method

This is very simple method in which, the farmers are enquired to estimate the area of their fields [13]. The enumerator and the farmer may visit all fields of the farmer and estimate the surface area by visual inspection. The method is low cost and less time consuming relatively but it is more subjective as it totally depends on farmer's knowledge and experience, there is more chance to misreport the crop area.

Optical Remote Sensing in Crop Mapping and Acreage Estimation

Remote sensing becomes an important tool as a modern method in crop mapping and acreage estimation has been widely adopted by many countries. Optical remote sensing has offered data for over four decades, with the ease of availability e.g., Landsat since 1972, the Landsat Thematic Mapper since 1983, Satellite Pour l'Observation de la Terre (SPOT) since the mid-1980s and the Moderate Resolution Imaging Spectroradiometer (MODIS) since 1999 [14]. Indian Remote Sensing (IRS) catering the data since 1988 with increase in spatial resolution from 188 m to 2.5 m and temporal capability from 24 day to 2 days at present. These voluminous data across the globe with different resolution and frequent revisit capability facilitate the near real time crop monitoring, mapping and acreage analysis. Optical remote sensing satellite sensors have the potential of obtaining multi-temporal and multi-spectral reflectance data over croplands that can be used for deriving time-series of vegetation indices (VIs) (Table 1), with the help of these vegetation indices and typical spectral reflectance's the discrimination of earth features becomes more easy. There are three broad approaches for remote sensing to generate crop map and acreage estimation i.e., a) Remote sensing forms a base for estimating parameters of spatial variability through area frame sample design. It provides an efficient and low cost stratification based on crop proportion derived from visual interpretation or digital classification of satellite images; (b) Direct and independent estimation that uses satellite image and a recognition technique to estimate the crop area in a given region and (c) The use of remote sensing data as an auxiliary variable helps make the estimates based on ground surveys more precise and reduces the amount of the field data to be collected, if the precision to be reached is fixed. On the contrary, if the sample size is fixed, this approach provides higher precision of the estimate.

Table 1: List of common vegetation indices have been used crop mapping/feature discrimination

Index	Formulae	Author
Difference Vegetation Index (DVI)	NIR - Red	[50]
Green Difference Vegetation Index (GDVI)	NIR – Green	[51]
Green Normalized Difference Vegetation Index (GNDVI)	(NIR – Green) / (NIR + Green)	[52]
Normalized Difference Vegetation Index (NDVI)	(NIR – Red) / (NIR + Red)	[53]
Normalized Green (NG)	Green / (NIR + Red + Green)	[51]
Normalized Red (NR)	Red / (NIR + red + green)	[51]
Normalized Near Infrared (NNIR)	NIR / (NIR + red + green)	[51]
Ratio Vegetation Index (RVI)	NIR / red	[54]
Green Ratio Vegetation Index (GRVI)	NIR / green	[51]
Enhance Vegetation Index (EVI)	G * [(NIR – red) / (NIR + C1*red – C2*blue + L)] Where, G = 2.5, C1 = 6, C2 = 7.5, L = 1	[55]
Modified Soil Adjusted Vegetation Spectral Index (MSAVI-2)	[2*NIR + 1 - √(2*NIR+1)² - 8*(NIR – red)] / 2	[56]
Optimized Soil Adjusted Vegetation Index (OSAVI)	[(NIR – red) / (NIR + red +L)] * (1 + L) where L is a correction factor that equals 0.16 (the same equation as SAVI but with a correction factor of 0.16 instead of 0.5)	[57]

Green Soil Adjusted Vegetation Index (GSAVI)	[(NIR – green) / (NIR + green +L)] * (1 + L), where L = 0.5	[51]
Infrared Percentage Vegetation Index (IPVI)	NIR / NIR + Red	[58]

Crop Mapping and Acreage Estimation Using MODIS Sensors

MODIS data forms the basis for numerous land use and land cover (LULC) mapping and analysis frameworks at regional scale [15]. Compared to other satellite sensors, the spatial, temporal and spectral specifications of MODIS are considered as highly suitable for LULC classifications which support many different aspects of social, environmental and developmental research [15]. Rice crop mapped on the large area of six South Asian Countries using time series MODIS data for the time period 2000 to 2001 [16]. The resulting rice maps and statistics are compared against a subset of independent field-plot points and the best available sub-national statistics on rice areas for the main crop growing season (*kharif* season). A fuzzy classification accuracy assessment for the 2000 to 2001 rice-map product, based on field-plot data, demonstrated accuracies from 67% to 100% for individual rice classes, with an overall accuracy of 80% for all classes. Acreage estimated of Australian dry land wheat crop for biomass estimation using MODIS NDVI and crop models. The results support the notion for extending the value of the MODIS NDVI using crop simulation models [17]. The combination of remotely sensed and simulation data might offer regional maps of spatial above ground biomass. Time series MODIS reflectance product used to derive vegetation phenology to identify soybean and corn based on crop calendar in the state of Parana, Brazil for crop years 2010-2015 [18]. Results suggested that the mapped areas of soybean and corn agreed with official statistics at the municipal level. The resultant map in the crop year 2012 was evaluated using an independent reference data set, and the overall accuracy and Kappa coefficient were 87.2% and 0.804 respectively.

Crop Mapping and Acreage Estimation Using Landsat Sensors

The application of Landsat images for global agricultural mapping and monitoring began in 1972 and has been used in domestic agricultural application as an input for field level management. The open data policy of United State Geological Survey for Landsat imageris influenced the agricultural applications particularly in crop acreage and production forecast estimate with the vast number of users across the world [19]. Now days the modern countries rely on satellite imagery as primary sources for developing crop acreage estimates. The combination of red, near infrared (NIR), and short-wave infrared (SWIR) bands with moderate resolution of 30 m and 8 days temporal capability of Landsat makes ideal input in crop discrimination and acreage estimation using different classification algorithms [20]. The moderate resolution and short period of revisit of Landsat found much ideal for crop acreage estimation on District and Block level even in multi cropped area. Several studies using Landsat data for identification of crops like cotton, rice, wheat, sugarcane, pulse crop, sorghum, maize, soybean etc and their acreage estimation has been documented [3, 21, 22, 23, 24, 25]. Xu, *et al*., [26] carried out cropland mapping along the Nile in Egypt over the past three decades (1984–2015) using 961 Landsat TM/ETM+/OLI images. Spectral features of selected growing season images and band ratio-based indices were used in supervised classification and reported that the overall classification accuracy of cropland was greater than 90 per cent. Kussul *et al*., [27] applied particular multilayer perceptrons (MLPs) technique for regional scale crop classification using multi temporal Landsat-8 images for the JECAM test site in Ukraine for the year 2013. It was reported that ensemble of MLPs provides better performance than a single neural network in terms of overall classification accuracy, kappa coefficient, and producer's and user's accuracies for separate classes.

Crop Mapping and Acreage Estimation Using Indian Satellite Sensors

In India, the crop identification and mapping was started around in 1969 by Indian Space Research Organization (ISRO) and Indian Council of Agricultural Research (ICAR) using aerial false colour photograph over Kerala [28]. Studies using remote sensing employed visual mapping of crops such as wheat [29] and rice [30]. Consequently, the satellite based studies graduated from visual to digital analysis and by launch of IRS-1A, projects such as Crop Acreage and Production Estimation (CAPE) was implemented covering large area crop inventory and yield modeling for important crops such as wheat, rice, cotton, groundnut, sorghum and mustard. The CAPE project was established under the Remote Sensing Applications Mission (RSAM) with engorged scope and objectives was formulated in 1986. Rigorous efforts have been made under this programme to develop methodology applicable over large areas [31]. A large body of experience has been gained in CAPE project on efficient sample design, factors affecting crop discrimination, spectral-yield relationships and realization of timeliness and accuracy for pre- harvest crop forecasts. Understanding of user requirements and various limitations in CAPE project has led to formulation of a proposal called FASAL (Forecasting Agricultural Output Using Space, Agrometeorology and Land-based Observations) to meet the precise requirements of multiple, nation-wide and multi-crop forecasts, in the same line satellite digital data was used for wheat acreage estimation in Karnal district of Haryana State as an early attempt in India [5, 32]. National inventory of *rabi* pulse crop using remotely sensed data coupled with fortnightly NDVI products was carried out effectively with more than 95% accuracy [24]. Similarly, Campbell *et al*. [33] has evaluated direct use of temporal spectral data for wheat acreage estimation in Australia. Vyas *et al*. [34] carried out multi crop identification in *rabi* season using IRS-1C/D LISS-III (Nov. 10, 2001, Dec. 12, 2001, Jan. 21, 2002 and Feb. 14, 2002) in geospatial domain and found most suitable techniques having RD (Relative Deviation) less than +_ 10% at tahsil level and this shows clear discrimination between the crops in study area of Bagh and Agra sadar tahsil of Agra District, Uttar Pradesh, India. Qinghan *et al*. [35] used the satellite data of different resolutions for crop area assessment in North China Plain. They demonstrated the usefulness of LANDSAT TM and IRS-P6 AWiFS (Advance Wide Field Sensor) and found that the appearance of high resolution sensors with large swath widths such as IRS-P6 AWiFS provides data appropriate for crop mapping on much larger areas. Maurya *et al*., [36] mapped soybean crop using MODIS (TERRA) satellite data and GIS database. MODIS (Moderate-Resolution Imaging Spectroradiometer) satellite image offers a large choice of opportunities for operational application in a large area. Integrating MODIS data with GIS techniques and time series based assessment (June 1st week to October 2nd week) the actual areas of soybean fields have been mapped and yield production have been predicted with 7% increase in accuracy over the previous year. Goswami *et al*., [37] demonstrated application of remote sensing and GIS technologies for the wheat acreage estimation for Indore District, Madhya Pradesh. Single date, cloud free Resourcesat -1 LISS- III digital data coinciding with flowering stage of wheat crop was used for acreage estimation. Wheat acreage was estimated district level and estimate was compared with LRC (Land record Commissioner) and found that RD% deviated from +19. Kumar *et al*. [38] successfully used Landsat-8 multi-date satellite images of 2014 to map the rice and cotton crop, he found well seperability amongst these crops as the cotton act as long duration crop. Using NDVI time series data derived from multi-date IRS P6 AWiFS of *rabi* season 2012-13. Pimpale *et al*. [39] classified wheat crop in dominant wheat growing districts of Maharashtra state and estimated the wheat area of 18,9481 ha, which is deviating by 9.78% from the reference data as reported by Government of Maharashtra. Similarly, Rajak *et al*., [40] made an attempt for early estimation of crop sown area using high temporal coarse spatial resolution data and low temporal fine spatial resolution data in Gujarat state (India) for 2011-12 *rabi* season. Multi-date data and two-date Resourcesat-2 AWiFS data up to mid-December were used for crop sown area early estimates and spatial distribution of crop and non-crop fields were obtained. Reddy *et al*. [41] explored the potential use of high resolution data for inventory of citrus orchards using LISS-IV and Cartosat data to classify citrus in Indi Hobli of Bijapur district, Karnataka, India and reported around 85% of accuracy in crop identification and mapping.

Discussion

Crop mapping is the identification of crops and its extents on the earth surface. Every crop having specific climatic requirements and duration to complete its life cycle and accordingly it makes phenotype that behave differently in the environment, that makes remote sensing more compatible to fetch its reflection differently in different electromagnetic spectrum bands. Advancement in remote sensing, the earth information gets collected in wide range of spectral bands with the regular intervals with the help of multispectral band images. The researchers tried to separate out the each crop grown on the earth surface by applying visual or digital image interpretation techniques. Major agricultural programmes monitoring agriculture in the world are Global Agricultural Monitoring (GLAM) [42], Monitoring Agricultural Resources through Remote Sensing (MARS) [43], FAO Global Information and Early Warning System (GIEWS) (http://fao.org/gviews), China Crop Watch System (CCWS) (http://www.cropwatch.com.cn/en/). These agencies are responsible to map different crops to have crop statistics that serves numerous purposes related to planning in agriculture and allied sector. The review shows potentials of optical data in crop mapping and crop acreage estimation It involved in land use/land cover mapping and area estimation category wise with the ability to view the earth surface in the spectral range 0.4 to 2.5 µm [21]. Most commonly used satellite data includes; Landsat, SPOT-VGT, NOAA/AVHRR, MODIS, IRS-P6-AWiFS, LISS-III, LISS-IV, Sentinel-2 etc. A number of studies have explored the usefulness of optical remote sensing to identify crop and crop areas estimation (Table 2). Some of the studies suggested the combination of optical and microwave data for better discrimination of crop to get higher accuracy in crop mapping and acreage estimation.

Table 2: Methodology and optical sensors used by different researchers in crop acreage estimation

Sensor	Methodology adapted	Crop	Result	Author
Landsat MSS	Two classification schemas was used in which, the first one was the use of maximum likelihood classifier for generating the rice maps. The second one was the use of a vector classifier using two nodes (*i.e.*, water and green canopy response).	Rice	Between the two schemas, the vector classifier was found to have better agreements (*i.e.*, ~94%) during the calibration phase over New South Wales, Australia	[59]
Landsat 8	Multi-temporal data using pixel based Unsupervised K-Means classification technique	Cotton	The image taken on Oct-2014 provided overall 98.81% accuracy with Kappa coefficient 0.9801 and image taken on Nov-2014 has provided overall 96.18% accuracy with Kappa coefficient 0.9436 for K=10	[60].
MODIS	Generated a potential rice cultivation area by digitizing a hardcopy land use map, and then used to mask two NDVI images acquired during early and late stage of rice plantation. Finally, maximum likelihood classifier was applied on the combined image for extracting the rice area.	Rice	Observed an overall accuracy of 95.7% over Zhejiang, China	[61]
IRS LISS-III	Used two images per year comprising of G, R, and NIR acquired during the early and vegetative stages of rice. Maximum likelihood classifier method was employed in combination of fiels survey data.	Rice	Found a good relationship between: (i) classified image and GPS measured area (*i.e.*, *r*2 value of 0.91); and (ii) eye estimates and actual measurement (*i.e.*, *r*2 value of 0.95)	[62]
IRS LISS-III	(i) digital elevation model to calculate the slope classes and considered the classes between 0%–25% slopes; (ii) multi-date LISS and land use maps to identify rice cultivation	Rice	The use of LISS improved the assessment, *i.e.*, additional 746.44 km2 potential rice areas were identified over Mizoram, India	[63]

	areas; (iii) soil maps to extract suitable soils for rice crop. Finally all of the layers were overlaid to generate potential rice areas.			
IRS AWiFS	Iterative Self-Organizing Data Analysis Technique (ISODATA) based clustering of the multi date NDVI dataset	Rape seed	It is possible to map the spatial distribution of Rape seed of different growing period as early, timely and late sown	[64]
IRS AWiFS	Iterative Self-Organizing Data Analysis Technique (ISODATA) based clustering of the multi date NDVI dataset	Sugarcane		[65]
IRS AWiFS	Iterative Self-Organizing Data Analysis Technique (ISODATA) based clustering of the multi date NDVI dataset	Cotton		[66]
IRS LISS-III / IV	frequency distribution curve method has been used and frequency range has been decided to discriminate wheat pixels from other pixels in hilly region	Wheat	Result shows deviation for acreage estimation from BES is around 3.28%.	[67]
SPOT/TM	Consistency analysis model	Rice	Consistency analysis model can provide a higher accuracy in extracting plant area from middle and low resolution satellite images, not only in total quantity but also in spatial distribution	[68]
Quick Bird	Miximum-likelihood classifier/Multi-layer perceptron neural network	Multiple crops	Classification successfully carried out with 87% accuracy	[69]
IRS AWiFS	Iterative Self-Organizing Data Analysis Technique (ISODATA) based clustering of the multi date NDVI stacked dataset	*Rabi* Pulse crop	Pulse crops accuracies of more than 95% was observed in contiguous areas and 50–80.77% in scattered regions	[24]
IRS LISS-IV	integrated approach methods based on texture property with different vegetation indices for single date	Multiple crops	LISS IV imagery can be effectively implemented to produce classified maps with higher accuracy	[4]

Advantages of Optical Remote Sensing in Crop Acreage Estimation

Optical remote sensing has been used for monitoring the state of the world's agricultural production, including identifying and differentiating most of the major crop types and conditions. Many studies have reported on the use of airborne optical multispectral imagery to estimate crop parameters such as leaf area index, canopy temperature, and plant height. These studies examined the relationship between crop condition and spectral response to determine whether these images could be used to estimate various crop condition parameters. Number of statistically significant correlations exists between the image reflectance and the crop condition parameters and these correlations vary as a function of crop type, time, and crop health. The results suggest that in many cases, multi-spectral optical imagery have edge in monitoring variations in crop conditions across the growing season for a variety of crop types [44]. Optical remote sensing provides high resolution images with high frequency of temporal resolution, which helps in frequent monitoring of crops. The quantification of crop condition is much easier in optical image than radar data, also it is less expensive comparatively microwave data when acquired of large geographic area [21].

Limitations of Optical Remote Sensing in Crop Acreage Estimation

Optical remote sensing images like, MODIS, AVHRR, SPOT-VGT, AWiFS have relatively low spatial resolution (i.e., in the range of 56 m to 1 km). This particular issue would be critical as the size of some rice fields might be smaller than the spatial resolution of the images. In the context of spatial resolution, the use of Landsat imagery would compensate the spatial resolution. Also, temporal resolution (i.e., 16 days) of the Landsat images and its swath coverage (i.e., approximately 180 km) might restrict their application in rice mapping. In application of optical remote sensing, at times it would be very difficult to obtain cloud-free images over some of the rice growing regions. These impose a problem for rice mapping especially when the period of interest falls in rainy season and during which heavy cloud greatly influences the image quality [45, 46, 47, 48, 49]. In India majority of rice crop grown in *kharif* season i.e. during the month of June to October, it is very difficult to get cloud free images during the early growth period of rice as the heavy rainfall period.

Conclusions

The present reviews demonstrate that the optical remote sensing can be engaged equally in different crop mapping and acreage estimation. In terms of the crop mapping in the kharif season using optical remote sensing found somewhat difficult. While the different crops mapping using remote sensing there are numerous challenges like cloud free data availability, data acquisition, spatial and spectral resolution, development of appropriate methodology adopted. In tropical conditions like India, it is found difficult to obtain cloud free data in *kharif* season particularly for rice mapping, but multi-date images can ease this problem to the great extent. The integration of optical with microwave remote sensing would be more beneficial for better accuracy in different crop mapping and acreage estimation as per the studied reviews. Also the development of image classification methods must be effective, efficient, and easy to implement for operational mode.

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