USE OF REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM FOR MANAGEMENT AND PLANNING OF POTATO PRODUCTION IN INDIA

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Introduction

Potato (Solanum tuberosum L.) plays an important role in food and nutritional security of India. Its contribution to the national economy is manifold. It has potential for export as seed as well as ware produce or as processed products. Though potato production has increased significantly over the last few decades, there is still a vast scope for increase in area, productivity and production. Assessment of crop condition, acreage and production in advance has a strong bearing on management and planning of potato production. Being a semi-perishable crop, its post harvest management needs special attention. Thus, an end-to-end management plan from sowing to harvest and storing to marketing is essential for sustained growth of potato crop in the country. This paper highlights the use of remote sensing and geographic Information System (GIS) in realizing many of these requirements of potato production in India.

Remote sensing has been recognized now as a valuable tool for viewing, analyzing, characterizing, and making decisions about our natural resources. From a general perspective, remote sensing is the science of acquiring and analyzing information about objects or phenomena from a distance. Today, satellite-borne sensors are used that exploit the full range of Electro Magnetic Radiation (EMR) from visible light, near-, mid-, and far infrared (thermal), microwave, and long-wave radio energy. The capability of multiple sources of information is unique to remote sensing. Of specific interest is the spectral, temporal, and spatial resolution. Spectral resolution refers to the width or range of each spectral band being recorded. We know that each target affects different wavelengths of incident energy differently - they are absorbed, reflected or transmitted in different proportions. Each band of information collected from a sensor contains important and unique data.

Table 1 highlights the spectral region and its property.

<table>
<thead>
<tr>
<th>Region</th>
<th>Wavelength</th>
<th>Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible (blue, red, green)</td>
<td>0.4-0.7mm</td>
<td>Reflectance</td>
</tr>
<tr>
<td>Reflective Infrared</td>
<td>0.7-3.0nm</td>
<td>Reflectance</td>
</tr>
<tr>
<td>Thermal Infrared</td>
<td>3.0-15.0mm</td>
<td>Radiative temperature</td>
</tr>
<tr>
<td>Microwave</td>
<td>0.1-30 cm</td>
<td>Brightness temperature (Passive)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Backscattering (Active)</td>
</tr>
</tbody>
</table>

Commonly used land resource remote sensing devices operate in the green, red, and near infrared regions of the electromagnetic spectrum giving a definite spectral signature of various targets due to difference in radiation absorption and reflectance of targets. These sensors are of particular use for vegetation by virtue of its notable absorption in the red and blue segments of the visible spectrum, its higher green reflectance and, especially, its very strong reflectance in the near-IR. Different types of vegetation show distinctive variability from one another owing to leaf and canopy architecture. These spectral variations facilitate to identify the crops and derive biophysical parameters for assessing crop condition and yield. Microwave sensors being sensitive to water content and roughness, provide many complimentary information of crop canopy, besides having the added advantage of day-night sensing. Often it takes more than a single sensor to adequately address the complex requirement of crop growth monitoring.

“Multitemporal information” is acquired from the interpretation of images taken over the same area, but at different times (taken days, weeks, years apart). This is of particular significance to study vegetation phenology, cropping pattern, crop rotation and crop condition.

Spatial resolution refers to the discernible detail in the image. Finer ones address local area studies, while coarser ones are preferred for regional/global monitoring studies. Today images are available that provide data from 1m to 1km spatial resolution and can be used for field level to block/district/state level crop studies.
Since the launch of the first earth observation satellite Landsat in July 1972, satellite remote sensing has progressed tremendously. In Indian context, the launch of the first land resource satellite IRS (Indian Remote Sensing Satellite) -1A in 1988, provided data from two sensors: LISS I (Linear Imaging Self Scanning I) with 72.5 m spatial resolution and LISS II (36.25 m resolution). Since then, a series of satellites from 1B, 1C, 1D, P4, P6 have been launched. Currently, more than a dozen orbiting satellites exist that provide data in a range of spectral, temporal and spatial resolutions. Major satellites having optical multispectral sensors are Indian Remote Sensing (IRS) satellites Resourcesat/P6, U.S. Landsats Thematic Mapper (TM) and IKONOS, the French Systeme Probatoire d’Observation de la Terra (SPOT) High Resolution Visible (HRV) Sensor. The satellites that provide high temporal resolution but with coarse spatial resolution (500 m to 1 km) data are the U.S. National Oceanic and Atmospheric Administration’s Advanced Very High Resolution Radiometer sensor (NOAA-AVHRR), the SPOT vegetation (VGT) and MODIS.

Use of satellite remote sensing data in crop survey and monitoring has progressed a lot since the work carried out by USDA under Large Area Crop Inventory Experiment (LACIE) in 1974. To-day, the MARS programme (Monitoring Agriculture with Remote Sensing) developed at the Joint Research Centre (JRC) for the General Directorate of Agricultural of the Commission of European Communities (EEC) and Statistical Service of the European Communities, provides up-to-date agricultural information to European agriculture policy makers. Remote sensing data for agricultural applications has been given high priority in the Indian national space programme. Application of space-borne remote sensing in the field of agricultural crop inventory is in an advanced stage in India. Since 1987, state and district level forecasts for major crops in India are regularly obtained using remote sensing data under the Crop Acreage and Production Estimation (CAPE) project. The procedure that has evolved over the years is now well defined and standardized. District level forecast of major crops like wheat, mustard, cotton, sorghum etc. are being made at least one month before the harvest using high spatial resolution data like IRS LISS III acquired during the peak vegetative growth stage (Navalgund et al., 1991). The procedure has been fine-tuned to obtain multiple estimates of the wheat crop production using multi-date IRS AWIFS data as the crop growth progresses. Keeping in view the cloud cover problem during kharif season, microwave data from RADARSAT ScanSAR has been used to obtain multiple forecast of rice crop production at state level since 1998.

Besides the polar orbiting satellite sensors, there are the geosynchronous satellites that now provide a large number of weather parameters like rainfall, temperature, solar radiation, and geographic parameters like elevation, slope and aspect in spatial format that enables to model crop growth and land suitability.

**Inventory and acreage estimation**

Identification and classification of potato crop using IRS LISS I/II data was carried out during 1992-93. The results indicated more than 95% classification accuracy for major growing areas like Bardhman district in West Bengal (Panigrahy et al., 2001). Use of RADARSAT Standard beam SAR data also resulted more than 90% classification accuracy for potato crop in Bardhaman district (Panigrahy et al., 1999). Initial work to estimate potato area at state level using multi-date WiFS data, carried out during 2001, gave encouraging results for major potato growing states like West Bengal (Singh et al., 2002 a, b). These experiences led to the formation of a project on “Estimating potato production, early in the season using remote sensing” at Space Applications Centre (ISRO), Ahmedabad under the Remote Sensing Applications Mission project to estimate winter potato area at state and national level using multi-date WiFS data. The work was carried out in collaboration with the Central Potato Research Institute, Shimla. Digital image processing and statistical enumeration techniques were used to estimate crop area. The accuracy of estimate was further improved by including more districts under study area after the availability of AWIFS data from 2005-06 season. The 4 band multi-spectral data of AWIFS with 55 spatial resolution enabled identification of the crop area in districts having smaller crop proportion compared with the 188 m spatial resolution two band (red, NIR) WiFS data. Distinct signature of potato could be observed compared with other crops generally grown in the study areas in AWIFS data. Consequently, AWIFS data has been used to forecast potato acreage in Uttar Pradesh, West Bengal, Bihar, Punjab and Haryana during 1995-96. Total 88 districts (out of 152 potato growing districts) having more than 3000 ha crop area (42, 15, 12, 9, 8 and 1 districts, respectively in UP, WB, Bihar, Punjab and Haryana) were analyzed. Histogram of the classified image was drawn to estimate crop area in each cluster of districts. These were then extrapolated to state level acreage using standard statistical proportional estimation. In total, these districts contribute a little more than 92% potato area of the five states and around 90% of winter potato in India. Results could be obtained one month before the harvest. The classification accuracy was high (around 92-95%) in Gangetic West Bengal and Punjab as the potato crop is the single dominant crop during that period and grown under contiguous cultivation. Around 90% classification accuracy was obtained for predominant districts (> 15000 ha area) in UP and Bihar. LISS III data was found optimum to provide district/block level area estimates. Village level estimates had been obtained using 6 m LISS IV data (Fig. 1 and 2).
Crop calendar and growth

Potato is an herbaceous tuber crop grown as a sandwich crop in the winter season, either after the harvest of rainy season crop of paddy or maize or kharif fallows before the winter season crop of wheat. However, there is a spatial variation in crop calendar even within a district as the crop is sown over a wide range of dates as early and late crops. This spatial variation in crop calendar can be obtained using temporal remote sensing data. A well-developed canopy, generally, has high reflectance in NIR band (due to internal leaf structure) and low reflectance in red band (due to chlorophyll absorption). Red and NIR bands of multi-date data was used to generate Normalized Difference Vegetation Index (NDVI) images as per the equation:

\[
NDVI = \frac{(NIR-RED)}{(NIR+RED)}
\]

NDVI highlights the crop behavior using the radiance of red and NIR bands that are indicator of the chlorophyll and cellular condition of the plant, respectively. Thus, in the beginning with crop emergence, the NDVI increases, reaches the maxima with peak vegetation and then starts declining with senescence. This temporal spectral pattern can be modeled using statistical methods to generate the crop calendar. The similar approach using WiFS data has been carried out for the Indo-Gangetic region. It was observed that potato planting extends from mid-October in Punjab and Haryana to mid-December in West Bengal. The initial growth of potato crop is very fast and it attains full vegetative growth by 50-60 days after planting. The major fraction of potato crop generally attain maximum leaf area index in the first week of December in Punjab, Haryana and Western parts of UP, in the third week of December in eastern parts of UP and Bihar, and in the second week of January in case of West Bengal.

Crop growth parameters like peak vegetative stage, rate of greening and rate of senescence can be derived from the spectral growth profile that in turn can be related to crop vigour and yield. Alternately, the spectral parameters are related to crop biophysical parameters like Leaf Area Index (LAI), biomass, crop height etc. that is correlated to crop yield or used as input in crop growth simulation models.

Early forecasting of crop production

Potato being a commercial and semi-perishable crop, pre-harvest assessment of crop production is required for various policy decisions. Use of high temporal data like IRS WiFS and AWiFS enables to obtain a quick knowledge of the changes in area from year to year. Analysis showed that temporal AWiFS data is more suited to obtain early estimation of crop growth at state or regional level. This also enables to identify the locations having any appreciable increase or decrease in potato crop area both for pure pixels or mixed pixels. NDVI of the potato
pixels indicated the general vigour of the crop. A threshold NDVI value was used to signify the change in vigour of the potato crop.

**Post harvest management**

Potato being a semi-perishable crop, proper storage planning is required to match with crop production. Analysis shows that more than 80 per cent of cold stores in India are devoted to potato crop. Yet, there seems crisis mainly due to mismatch between location and allocation. Remote sensing and GIS provide a scientific basis to work out the total requirement and locations, which can cater to the potato growers. A pilot study in this direction was carried out for three major blocks in Bardhman district of West Bengal. Potato crop map was generated using remote sensing data. Average yield of potato in the three permanent sites were estimated from last five years yield data from Department of Agriculture, West Bengal and the production was calculated. Ancillary information on road network, power supply, village locations, and existing cold store facility was used in GIS environment to model the requirement of storage capacity and optimum locations. The analysis showed there is a need of at least 57 new cold storages to cater to the current production (Ray et al., 2000).

**Cropping system**

The concept of cropping system has been evolving during the last two decades for sustainable food production that has a balance between ecology and economy. Potato crop has a significant role in this approach. The crop is widely distributed from Indo-Gangetic plains to northern and southern hills and is grown as summer, autumn, winter and spring crop in one or the other part of India. It fits well in multiple cropping due to its short duration, flexibility of planting and harvesting besides its high commercial value. The crop also has the advantage of nutrient residues and tillage reduction in succeeding crop, amenability to geometric manipulations.

Satellite remote sensing has been used successfully to map the cropping pattern and crop rotations. Multi-date data acquired during different crop growth stages and crop seasons has been used to generate cropping systems vegetation dynamics, indices (Panigrahy and Sharma, 1997, Panigrahy et al., 2005)

**Crop intensification**

The production of potato could be increased through horizontal expansion by bringing more area under cultivation. The scope of such expansion depends on land available that is suitable to grow this crop. This calls for generation of regional as well as locale-specific action plans by integrating natural resources information obtained from satellite data in conjunction with collateral data. Site suitability index using required parameters like soil, temperature, moisture availability derived from remote sensing data can be used to assess suitability. The time and duration of land availability can be derived from crop rotation and crop calendar maps using remote sensing data. Thus, it is feasible to identify and characterize areas for growing potato. Such a concept has been used to identify suitable areas in Bardhaman district in West Bengal using soil texture, physiography and temperature parameters (Panigrahy and Chakraborty, 1998).

**Disease and pest management**

Pests and diseases are main sources of loss in economic yield in potato. The main requirement is detection when the disease is at low intensity and to assess disease damage. Work carried out so far has shown the feasibility of delineating potato by change detection method fields for damage by late blight (Arora et al., 2004). However, the challenges lie for early detection of disease for forewarning purpose. In this direction, hyper spectral remote sensing has a great role to play. Hyper spectral can provide spectral information in narrow bands of 1-5 nm in contiguous spectrum. Studies carried out using ground-based spectroradiometer with the spectral range of 325-1075 nm has shown encouraging results (Fig. 3). The optimal bands, in 400-1075 nm spectral range, for discrimination of late blight disease intensities were reported to be 540, 610, 620, 700, 710, 730, 780 and 1040 nm. This covered green, red, red edge and near infrared region, whereas for lower disease intensity up to 25% the red edge bands (710, 720 and 750 nm) could discriminate the diseased plants from healthy ones.

**Precision farming**

Precision farming has emerged as the need of the hour to optimize production taking into account the variability in time and space of any unit area. The concept becomes all the more important for horticulture crops in arid areas to optimize resource utilization and maximize the returns. A combined use of GIS and GPS to account the variation in soil nutrient status and microclimate provides a cost-effective and manageable tool to plan site-specific management. Such a concept has been validated for potato fields in Punjab (Parihar et al., 2002). The future remote sensing sensors like hyper spectral will play a crucial role in this field.
Conclusion

Image acquired by satellite sensors provides an important source of information for mapping and monitoring the natural and manmade features on the land surface. Applied terrestrial Remote Sensing involves the detection and measurement of electromagnetic energy (usually photons) emanating from distant objects made of various materials, so that the user can identify and categorize these objects by class or type, substance, and spatial distribution. Currently, more than a dozen orbiting satellites of various types provide data crucial to improving our knowledge of the Earth. The imaging satellite systems can be usefully classified into, (a) moderate swath, 5 to 30 meters spatial resolution and multiple spectral bands which act as back bone for mapping various classes at various scales, (b) narrow swaths, 1 meter or less panchromatic resolution, used for field level studies, (c) Hyper spectral sensors with 1-5 m spectral resolution and 30 meter spatial resolution (useful for crop management study like disease, nutrient, variety etc.) and (d) Radar with 5 to 10 meter resolution useful for kharif crops, moisture status, flood damage etc. These data support studies at village level to district, state and regional levels. Information on crop area, crop duration, crop vigour, crop rotation can be mapped using the data. Early forecast of the in-season crop production can be made for strategic decisions on import/export. Multi-year data can be used successfully to analyse the year-to-year changes in crop area and cropping pattern. The geosynchronous satellites provide weather parameters. The stereo sensors provide geographic parameters like elevation, slope, aspect and drainage. The spatial data format allows modeling these parameters in GIS to plan management issues like crop intensification, precision farming/high-tech management/contract farming and post-harvest management. The capabilities of all these sensors put together has a tremendous scope as a planning tool for all who are interested in knowing and keeping track of the details of what is going on and want to plan and monitor. The amount and quality of the land information data, which the land observing satellite fleet in 21st century will be capable of providing, may revolutionize both our scientific knowledge and our practical management of resources. The satellites are, however, only the first step. Their value can only be realized through the ingenuity and efforts of the users.

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Literature cited:


