Vegetation Stress Detection With Hyperspectral Remote Sensing for A Winning Agribusiness

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Abstract

The subject agribusiness has drawn an enormous attention by organized sector in national and multinational level with the recent move of the Government of India to allow Foreign Direct Investment (FDI) in the retailing sector. Technology driven efforts are very much important in this changed scenario to increase market efficiency reducing inventories, waste, and costs. Earth Observation Satellite (EOS) imagery driven Remote Sensing (RS) and Geographical Information System (GIS) technology can be utilized as a high-end Spatial Decision Support System (SDSS) to extract the different aspects of agriculture like land-use land-cover (LULC) condition, soil properties like moisture estimation, moisture conservation, crop identification, identification of suitable farming site for suitable crop, acreage estimation, crop monitoring, damage monitoring, and complete supply chain monitoring includes crop vehicle tracking integrating Global Positioning System (GPS). Increased availability of narrow band hyperspectral imagery from Hyperion sensor has prompted to explore hyeprspectral imagery to estimate the vegetation biophysical parameters and leaf biochemical used to detect nutritional and water stress condition. This paper summarizes the use of hyperspectral remote sensing for vegetation monitoring through biochemical and biophysical parameter estimation, discussing the potential for detecting water stress. Central to this objective is our primary research question: Can remote sensing play a key role to monitor agri-crop health to enhance the agribusiness efficiency?

Keywords: Vegetation Stress, Hyperspectral Remote Sensing, Vegetation Index, Agricultural Monitoring, and Agribusiness.

INTRODUCTION

In the post WTO regime, agriculture has become more industrialized, competitive and even more technology and management oriented. In recent years there has been a rapid industrialization of agriculture in the developed economies around the world. With the recent move of the Government of India to allow Foreign Direct Investment (FDI) in the retailing sector, the agribusiness in India becomes one of the focused areas for the national and international investors. Agribusiness has a direct impact on farm economy, food security, crop diversification, farm mechanization, value addition, agri-exports, and technology adoption. Agribusiness also deals with the trading of technology, human resources, services related to agro-products. Technology driven identification of production area, monitoring of crops, logistics networks, location of demand and optimal network for routing the agricultural products reduce inventories, waste, and costs, and thus increase efficiency within the market channel. Earth Observation Satellite Imagery driven Remote Sensing (RS) and Geographical Information System (GIS) technology can be utilized effectively in the different steps of agribusiness like land preparation, cropping, production, logistics, supply, and monitoring.

Since the launch of the first Earth Resources Technology Satellite (ERTS) 1972, remote sensing data has become integral to environmental monitoring and assessment throughout the world. During this time, we have seen analysis of the data from simple visual observations to sophisticated interpretations based on first principles of spectroscopy and electromagnetic radiation. The advent of digital multispectral satellite and airborne sensors

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stimulated the development of new computerized analytical tools and visualization methods, initiated thinking about detecting biogeochemical processes that are measurable in different regions of the electromagnetic spectrum (EM), including measuring the fluxes and storage of materials between the air, land, sea components of biogeochemical (BGC) cycles (Zarco-Tejada et al., 2007).

RESEARCH OBJECTIVES

Rapid industrialization in the Indian agriculture is expected in the coming years with the recent move of the Government of India to allow Foreign Direct Investment (FDI) in the retailing sector. Increasing market efficiency reducing inventories, waste and costs are a challenge for the national and international investors. Objectives of this research are mentioned below:

1. Monitoring vegetation health status seating in the office with a minimum resource, using satellite remote sensing techniques.
2. Use of hyperspectral remote sensing to monitor the biochemical and biophysical parameters of vegetation/ agricultural crops to detect the vegetation/agricultural stress area.

Figure 1: Vegetation Reflectance and Transmittance Spectra in Different Parts of EMR Spectrum

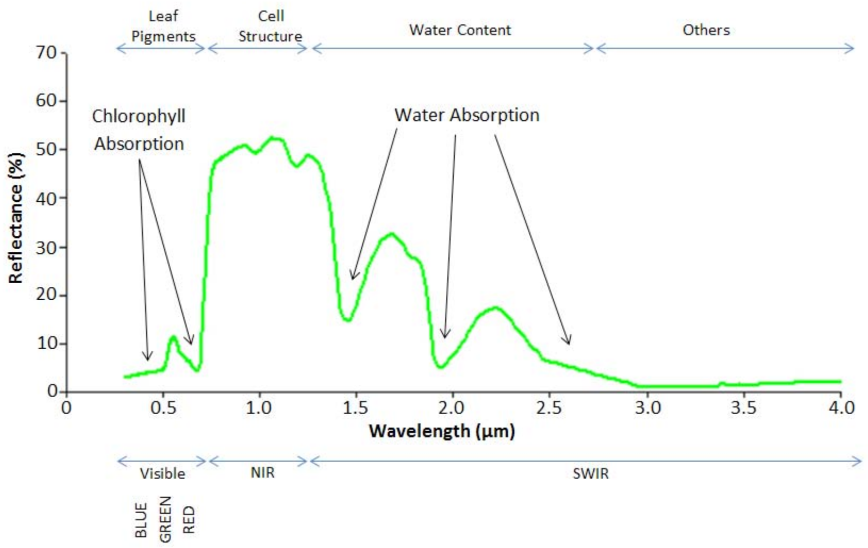
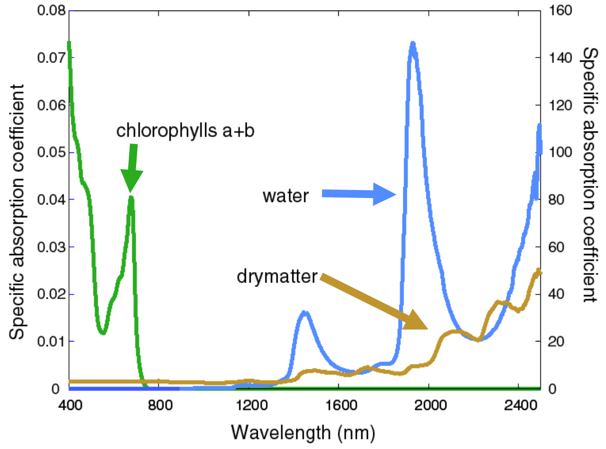


Figure 2: Absorption Intensity of Leaf Biochemical Constituents (e.g., C_{ab}, Water and Dry Matter)



3. Central to this objective is our primary research question: Can remote sensing play a key role to monitor agri-crop health to enhance the agribusiness efficiency?

SCOPE OF STUDY

Optical Reflectance and Plant Bio-Chemistry

Analyzing vegetation using remotely sensed data requires knowledge of the structure and function of vegetation and its reflectance properties. Vegetation reflectance properties are used to derive vegetation indices (VIs). VIs is constructed from reflectance measurements in two or more wavelengths to analyze specific characteristics of vegetation, such as total leaf area and water content. The solar-reflected optical spectrum 400 nm to 2500 nm region is routinely measured using a variety of optical sensors ranging from multispectral (e.g., Landsat TM) to hyperspectral (e.g., Hyperion). Vegetation interacts with solar radiation differently from other natural materials, such as soil and water bodies. The absorption and reflection of solar radiation is the result of many interactions with different plant materials, which varies considerably by wavelength, water, pigments, nutrients, and carbon, and they are each expressed in the reflected optical spectrum from 400 nm to 2500 nm, with often overlapping, but spectrally distinct, reflectance behaviors. These known signatures allow scientists to combine reflectance measurements at different wavelengths to enhance specific vegetation characteristics by defining VIs.

The optical spectrum is partitioned into four distinct wavelength ranges: the visible (400 nm - 700 nm) characterized by a strong absorption of light by photosynthetic pigments in a green leaf (Fig 2), the Near Infrared plateau (NIR) (700 nm - 1300 nm) where absorption is limited to dry leaf matter but where multiple scattering within the leaf, related to the fraction of air spaces, i.e., to the internal structure, drives the reflectance and transmittance levels, the Shortwave Infrared 1 (SWIR-1) (1300 nm – 1900 nm), and Shortwave Infared 2 (SWIR-2) (1900 nm - 2500 nm) which is also a zone of strong absorption, primarily by water in fresh leaves and secondarily, by dry matter (dry carbon compounds like cellulose and lignin, nitrogen, sugars, and other plant compounds) when the leaf wilts and dries. All of these observations and experimental measurements are a prerequisite to extracting biophysical information.

LITERATURE REVIEW

Vegetation stress is the result of complex physiological processes. Stress symptoms show up as photosynthesis decline (i.e., strain phase). Leaf Chlorophyll (C_{ab}) and other leaf biochemical constituents such as dry matter content (C_m) and water content (C_w) are indicators of plant stress and nutritional deficiencies associated with relative availability of elements N, P, K, Fe, Ca, Mn, Zn, and Mg, among others (Marschner et al., 1986; Fernandez-Escobar et al., 1999; Jolley et al., 1994; Chen et al., 1982; Wallace et al., 1991; Tagliavini et al., 2001). In this study hyperspectral Remote Sensing (RS) techniques, based on radiative transfer modelling from high number of contiguous spectral bands in the 400-2500 nm spectral region have been used successfully to derive meaningful biophysical variables related to plant status such as the concentration of foliar pigments (Marschner et al., 1986), Fernandez-Escobar et al., 1999), nitrogen concentration (Jolley et al., 1994), water content (Chen et al., 1982), and the Leaf Area Index (LAI), (Wallace et al., 1991). Photochemical Reflectance Index, PRI (Gutierrez-Rosales et al., 1992) has been integrated with traditional Vegetation Indices (VIs) exploiting biophysical variables affected during the damage phase to provide a strategic agricultural stress monitoring system.

Several vegetation indices proposed in the literature track and quantify chlorophyll concentration (Vogelmann et al., 1993; Gitelson et al., 1996; Carter et al., 1994; Zarco-Tejada et al., 2001), allowing remote detection methods to identify and map vegetation stress through the influence of chlorophyll content variation.

REMOTE SENSING OF PLANT BIO-CHEMISTRY

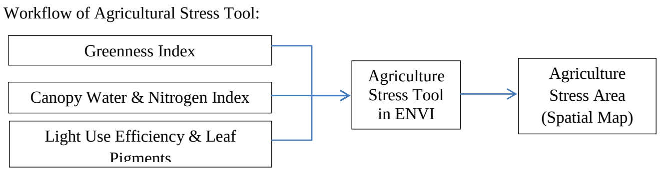
Photosynthetic assimilation rate is reduced when the plants exposed to a stress agent, and the fluorescence (i.e., dissipation pathways of excess energy) and heat dissipation related to Non-Photochemical Quenching, NPQ are modulated. Detection of fluorescence and NPQ modulation gives an indirect measure of the photosynthetic process, therefore information on stress experienced in the strain phase by plants. Agricultural stress tool designed in ENVI Software developed by Exelis Visual Information System (www.exelisvis.com) create a spatial map showing the distribution of crop stress. This tool uses the following VI category:

Table 1: Vegetation Indices

Vegetation Index	*Equation*	*Target*	*Reference*
Normalized Difference Vegetation Index (NDVI)	$\mathrm{NDVI} = \frac{R_{800} - R_{680}}{R_{800} + R_{680}}$	Greenness, LAI	Rouse et al., (1973)
Simple Ratio (SR)	$\mathrm{SR} = \frac{R_{800}}{R_{680}}$	Leaf Cab Concentration	Rouse et al., 1973 ; Tucker et al., 1979 ; Sellers et al., 1985
Enhanced Vegetation Index (EVI)	$\mathrm{EVI} = 2.5 \frac{R_{800} - R_{680}}{(R_{800} + 6) * (R_{680} - 7.5) * (R_{450} + 1)}$	Greenness, LAI	Huete et al., 1997
Atmospherically Resistant Vegetation Index (ARVI)	$\mathrm{ARVI} = \frac{(R_{800} - 2) * (R_{800} - R_{450})}{(R_{800} + 2) * (R_{800} - R_{450})}$	Greenness, LAI	Kaufman et al., 1996
Red Edge Normalized Difference Vegetation Index (NDVI_{RE}) [Chlorophyll Index (CI)]	$\mathrm{NDVI}_{705} = \frac{R_{750} - R_{705}}{R_{750} + R_{705}}$	Leaf C_{ab} Concentration	Gitelson et al., 1994 ; Sims et al., 2002
Modified Red Edge Simple Ratio (mSR)	$\mathrm{mSR} = \frac{R_{750} - R_{445}}{R_{705} - R_{445}}$	Leaf C_{ab} Concentration	Sims, D. A. et al., 2002 ; Datt et al., 1999
Modified Red Edge Normalized Difference Vegetation Index (mNDVI)	$\mathrm{mNDVI} = \frac{R_{750} - R_{705}}{R_{750} + R_{705} - 2 * R_{445}}$	Greenness, LAI	Sims et al., 2002 ; Datt et al., 1999
Vogelmann Red Edge Index	$\mathrm{VOG\,1} = \frac{R_{740}}{R_{720}}$ $\mathrm{VOG\,2} = \frac{R_{734} - R_{747}}{R_{715} + R_{726}}$ $\mathrm{VOG\,3} = \frac{R_{734} - R_{747}}{R_{715} + R_{720}}$	Leaf C_{ab} Concentration	Vogelmann et al., 1993
Photochemical Reflectance Index (PRI)	$\mathrm{PRI} = \frac{R_{531} - R_{570}}{R_{531} + R_{570}}$	C_{ar}/ C_{ab}	Gamon et al., 1992, 1997
Structure Insensitive Pigment Index (SIPI)	$\mathrm{SIP\ I} = \frac{R_{800} - R_{445}}{R_{800} - R_{680}}$	C_{ar}/ C_{ab}	Penuelas et al., 1995
Normalized Difference Nitrogen Index (NDNI)	$\mathrm{NDNI} = \frac{\log {}^{1}\!/_{R_{1510}} - \log {}^{1}\!/_{R_{1680}}}{\log {}^{1}\!/_{R_{1510}} + \log {}^{1}\!/_{R_{1680}}}$	Canopy Nitrogen	Serrano et al., 2002 ; Fourty et al., 1996
Carotenoid Reflectance Index (CRI)	$\mathrm{CRI1} = \frac{1}{R_{510}} - \frac{1}{\mathrm{R550}}$ $\mathrm{CRI\,2} = \frac{1}{R_{510}} - \frac{1}{R_{700}}$	Leaf C_{ab} Concentration	Gitelson et al., 2002

Vegetation Index	*Equation*	*Target*	*Reference*
Anthocyanin Reflectance Index (ARI)	$ARI\,1 = \frac{1}{R_{550}} - \frac{1}{R_{700}}$ $ARI\,2 = 800\,[\frac{1}{R_{550}} - \frac{1}{R_{700}}]$	Leaf C_{ab} Concentration	Gitelson et al., 2001
Water Index (WI)	$WI = \frac{R_{900}}{R_{970}}$	Leaf Water Content	Penuelas et al., 1999; Champagne et al., 2001
Normalized Difference Water Index (NDWI)	$NDWI = \frac{R_{857}}{R_{857}} - \frac{R_{1241}}{R_{1241}}$	Leaf Water Content	Gao et al., 1995
Moisture Stress Index (MSI)	$MSI = \frac{R_{1599}}{R_{819}}$	Leaf Water Content	Hunt et al., 1989 ; Ceccato et al., 2001
Normalized Difference Infrared Index	$NDII = \frac{R_{819} - R_{1649}}{R_{819} + R_{1649}}$	Leaf Water Content	Hardisky et al., 1983 ; Jackson et al., 2004
MERIS terrestrial chlorophyll index (MTCI)	$MTCI = \frac{R_{735.75} - R_{705}}{R_{705} + R_{681.25}}$	Leaf C_{ab} Concentration	Dash et al., 2004
(Red Edge Position (λRE)	Red edge λ at which $\lambda_{RE} = \frac{R_{max} + R_{min}}{2}$	Leaf C_{ab} Concentration	Holder et al., 1983 ; Curran et al., 1990
Plant Senescence Reflectance Index (PSRI)	$PSRI = \frac{R_{680} - R_{500}}{R_{750}}$	$C_{ar}/\ C_{ab}$	Merzlyak et al., 1999
Yellowness Index (YI)	$YI = -\frac{R_{580} - 2 * R_{624} + R_{668}}{0.044^2}$	$C_{ar}/\ C_{ab}$	Adams et al., 1999
WI/ NDVI	$WI/NDVI = \frac{R_{900}}{R_{970}} \Big/ \frac{R_{800} - R_{680}}{R_{800} + R_{680}}$	Canopy Water Content	Colombo et al., 2004
Normalized Difference Lignin Index (NDLI)	$NDLI = \frac{\log 1/R_{1754} - \log 1/R_{1680}}{\log 1/R_{1754} + \log 1/R_{1680}}$	$C_{ar}/\ C_{ab}$	Serrano et al., 2002 ; Fourty et al., 1996 ; Melillo et al., 1982
Cellulose Absorption Index (CAI)	$CAI = 0.5\ \ (R_{2000} - R_{2200} - R_{2100}\ )$	$C_{ar}/\ C_{ab}$	Daughtry et al ., 2001; Daughtry et al., 2004

Figure 3: Workflow of Agricultural Stress Tool



STUDY AREA

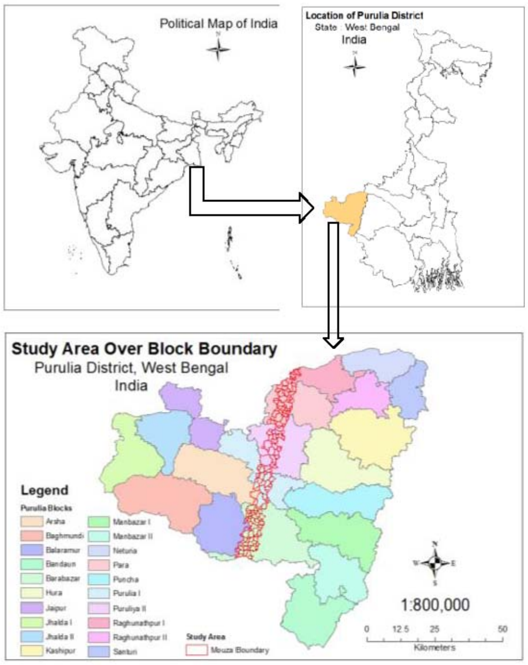
Study has been carried out on 177 mouza in the Purulia District, West Bengal which is situated in the eastern part of Chhotanagpur plateau area where agriculture plays the predominant role for socio-economic condition. Although the panchayats or local governing councils are well developed and land reform has been actively implemented, the district have a high poverty rate due to irregular agriculture production, unorganized supply

Table 2: Vegetation Indices Category Used in Agriculture Stress Tool

VI Category		*Vegetation Indices*
Greenness Index	Broadband Greenness	NDVI, SRI, EVI, ARVI, SGI (Sum Green Index)
	Narrowband Greenness	NDVI$_{RE}$, $_{m}$SR, $_{m}$NDVI, VOG1, VOG2, VOG3, REP (Red Edge Position)
Canopy Water & Nitrogen Index	Canopy Water Contents	WI, NDWI, MSI, NDII
	Canopy Nitrogen	NDNI
Light Use Efficiency & Leaf Pigments	Light Use Efficiency	PRI, SIPI, RGRI (Red Green Ratio Index)
	Leaf Pigments	CRI1, CRI2, ARI1, ARI2

chain management, resource constraint, including small firm size, lack of infrastructure to preserve the agri-food products, non-availability of proper market, lack of information regarding food safety, quality etc.. Suicide due to poverty and malnutrition are common occurrence specifically from the Schedule Casts (SC) and Schedule Tribes (ST). Disparities in poverty incidence are rising and are likely to be exacerbated by the actions of armed groups like the Naxalites and Maoist rebels.

Figure 4: Study Area



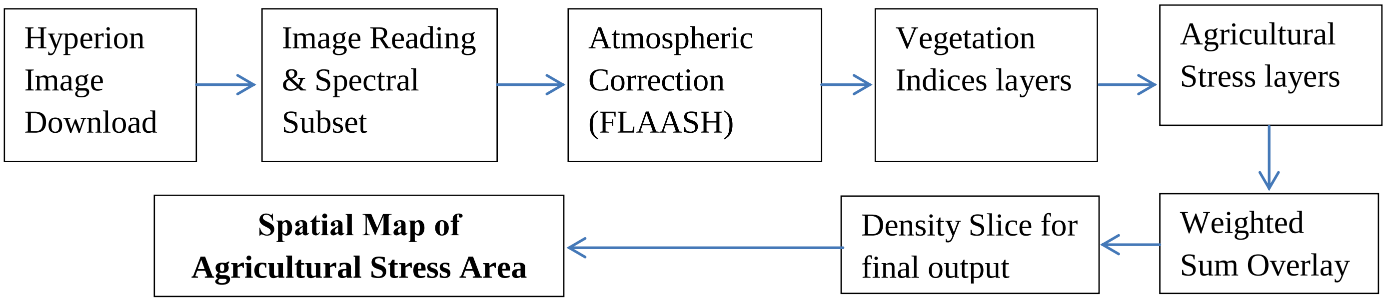
METHODOLOGY

A case study has been carried out over 177 mouza on the study area as highlighted in Fig. 3. Hyperion satellite image in Geotiff format that contains 242 bands has been downloaded from USGS website http://earthexplorer.usgs.gov/. Image reading, spectral subset of bad bands and atmospheric correction using “Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH)” algorithm has been carried out in ENVI software. Output reflectance of Hyperion image has been used within Vegetation Index Calculator tool of ENVI to generate different layers of VIs required for agricultural stress detection. Twenty five numbers of VIs generated using Vegetation Index Calculator are used in Agricultural Stress Tool. All possible combination has been used and it generates 224 numbers spatial layers of agricultural stress. Each layer with ten classes value 0 to 10, where class value 0 (zero) is unclassified, value 1 is least stressed area and value 9 is maximum stressed area. All agricultural stress layers, which are 224 in number, have been used in the “Weighted Sum Overlay” algorithm in ArcGIS software to generate a combined single layer from 224 layers. Output raster layer has been sliced into ten levels i.e., from unclassified to least stressed area to maximum stressed area. Spatial subset of output raster is done using the boundary vector layer of study area to generate the output for study area only.

RESULT AND DISCUSSION

In this case study vegetation stress detection using geospatial technology has been presented. Results showed that spectral observations improve vegetation monitoring providing information on vegetation biochemical and physiological status. The use of narrow spectral indices affected by vegetation physiological processes (i.e., photosynthesis) integrated with more traditional VIs allowed to study the development of vegetation stress from the strain phase to the damage phase with promising results in vegetation stress early detection. Agricultural stress tool in ENVI have been explored. Different VIs extracted from Broadband Greenness, Narrowband

Figure 5: Workflow of the Methodology



Greenness, Canopy Water Contents, Light Use Efficiency and Leaf Pigments have been explored in detail for the ultimate detection of stress. Spatial output is summarized in the (Fig. 5 to Fig. 10). Output result compared with the image in a standard false color combination (FCC), which shows an impressive result.

LIMITATIONS

Our initial experiments have been conducted on comparatively small area due to non-availability of hyperspectral image. In this study we have used open source low resolution hypersperctral image from experimental satellite sensor hyperion. High resolution airborne hyperspectral image may provide more spatial accuracy. Non availability of temporal images is another limitation. Accuracy assessment carried out using historical records and visual interpretation with standard false color combination (FCC) images.

MANAGERIAL IMPLICATIONS

In spite of many limitations the research output shows very impressive results to identify vegetation stress area. Application of remote sensing is cost effective than the conventional vegetation monitoring using manual survey. Gaps of sample survey can also be avoided using the remote sensing. Geographical Information System (GIS) in addition to Remote Sensing (RS) technology can be utilized as a high-end Spatial Decision Support System (SDSS) and Management Information System (MIS) to extract and disseminate the different aspects of agriculture to the decision makers on as when required basis.

DIRECTION OF FUTURE RESEARCH

One can use aspects like the historical rainfall, temperature, and Potential Evapotranspiration (PET), data from Indian Meteorological Department (IMD), agro-climatic zone to create in micro level. Besides, one can also use other resources like the latest LULC map from satellite image, soil resource map and digital elevation model agro-edaphic zone to create in micro level. Agro- ecological zone can be created to identify right crop in right area combining agro-climatic zone map and agro-edaphic zone map in a weighted overlay techniques in GIS platform.

CONCLUSION

From the result of our initial experiments it is evident that the geospatial technology may be an important tool for the decision makers of agri-business community to monitor the vegetation health status in a cost effective manner. Considering the pattern and trend of health status crop acreage estimation is also possible in geospatial environment. So it can be concluded that the remote sensing technology may play a key role to monitor agri-crop health to enhance the agribusiness efficiency.

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