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Applications of Remote Sensing in Agriculture - A Review

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A B S T R A C T

Remote sensing has several advantages in the field of agronomical research purpose. The assessment of agricultural crop canopies has provided valuable insights in the agronomic parameters. Remote sensing play a significant role in crop classification, crop monitoring and yield assessment. The use of remote sensing is necessary in the field of agronomical research purpose because they are highly vulnerable to variation in soil, climate and other physico- chemical changes. The monitoring of agricultural production system follows strong seasonal patterns in relation to the biological life cycle of crops. All these factors are highly variable in space and time dimensions. Moreover, the agricultural productivity can change within short time periods, due to unfavourable growing conditions. Monitoring of agricultural systems should be followed in timely. Remote sensing are important tools in timely monitoring and giving an accurate picture of the agricultural sector with high revisit frequency and high accuracy. For sustainable agricultural management, all the factors which are influencing the agricultural sector need to be analysed on spatio-temporal basis. The remote sensing along with the other advanced techniques such as global positioning systems and geographical information systems are playing a major role in the assessment and management of the agricultural activities. These technologies have many fold applications in the field of agriculture such as crop acreage estimation, crop growth monitoring, soil moisture estimation, soil fertility evaluation, crop stress detection, detection of diseases and pest infestation, drought and flood condition monitoring, yield estimation, weather forecasting, precision agriculture for maintaining the sustainability of the agricultural systems and improving the economic growth of the country.

Introduction

Remote sensing is the art and science of gathering information about the objects or area of the real world at a distance without coming into direct physical contact with the object under study. Remote sensing is a tool to monitor the earth's resources using space technologies in addition to ground observations for higher precision and accuracy. The principle behind remote sensing is the use of electromagnetic spectrum (visible, infrared and microwaves) for assessing the earth's features. The typical responses of the targets to these wavelength regions are different, so that they are used for distinguishing the vegetation, bare soil, water and other similar features (refer figure 1). It can also be used in crop growth monitoring, land use pattern and land cover changes, water resources mapping and water status under field condition, monitoring of diseases and pest infestation, forecasting of harvest date and yield estimation, precision farming and weather forecasting purposes along with field observations. In essence, remote sensing techniques are used for earth's resources sensing. Remote sensing data can greatly contribute to the monitoring of earth's surface features by providing timely, synoptic, cost-efficient and repetitive information about the earth's surface (Justice *et al.,* 2002). It also has several applications in the field of agro-meteorological purpose. Remote sensing inputs combined with crop simulation models are very useful in crop yield forecasting. Since the ground based and air based platforms are time consuming and have limited use, these space based satellite technologies are gaining more importance for acquiring spatio-temporal meteorological and crop status information for complementing the traditional methods.

Agricultural applications – Basic aspects

During the early stages of the satellite remote sensing, most researchers are focused on the use of data for classification of land cover types with crop types being a major focus among those interested in agricultural applications. In recent years, the work in agricultural remote sensing has focused more on characterization of plant biophysical properties. Remote sensing has long been used in monitoring and analyzing of agricultural activities. Remote sensing of agricultural canopies has provided valuable insights into various agronomic parameters. The advantage of remote sensing is its ability to provide repeated information without destructive sampling of the crop, which can be used for providing valuable information for precision agricultural applications. Remote sensing provides a cheap alternative for data acquisition over large geographical areas (De beurs and Townsend, 2008). In India, the satellite remote sensing is mainly used for the crop acreage and production estimation of agricultural crops. Remote sensing technology has the potential of revolutionizing the detection and characterization of agricultural productivity based on biophysical attributes of crops and/or soils (Liaghat and Balasundram, 2010). Data recorded by remote sensing satellites can be used for yield estimation (Doraiswamy *et al.,* 2005; Bernerdes *et al.*, 2012), crop phenological information (Sakamoto *et al.,* 2005), detection of stress situations (Gu *et al.*, 2007) and disturbances. Remote sensing along with GIS is highly beneficial for creating spatio-temporal basic informative layers which can be successfully applied to diverse fields including flood plain mapping, hydrological modelling, surface energy flux, urban development, land use changes, crop growth monitoring and stress detection (Kingra *et al.,* 2016). The advances in the use of remote sensing methods are due to the introduction of narrow band or hyperspectral sensors and increased spatial resolution of aircraft or satellite mounted sensors. Hyperspectral remote sensing has also helped to enhance more detailed analysis of crop classification. Thenkabail *et al.,* (2004) performed rigorous analysis of hyperspectral sensors (from 400 to 2500 nm) for crop classification based on data mining techniques consisting of principal components analysis, lambda–lambda models, stepwise discriminant analysis and derivative greenness vegetation indices. Many investigations have included different types of sensors which are capable of providing the reliable data on a timely basis on a fraction of the cost of traditional method of data gathering.

Monitoring of vegetation cover

The science of remote sensing play a vital role in the area of crop classification, crop acreage estimation and yield assessment. Many research experiments were done using aerial photographs and digital image processing techniques. But the field of remote sensing helps in reducing the amount of field data to be collected and improves the higher precision of estimates (Kingra *et al.,* 2016). The ability of hyper spectral data to significantly improve the characterization, discrimination, modeling, and mapping of crops and vegetation, when compared with broadband multispectral remote sensing, is well known (Thenkabail *et al.,* 2011). This was helpful in establishing the 33 optimal HNBs and an equal number of specific two-band normalized difference HVIs are used to characterize, classify, model and map and also to study specific biophysical and biochemical quantities of major agricultural crops of the world (Thenkabail *et al.,* 2013). In relative to the crop condition, some remote sensing techniques are more focused on physical parameters of the crop system such as nutrient stress and water availability in assessing the crop health and yield. And other researchers are focused more on synoptic perspectives of regional crop condition using remote sensing indices. The most commonly used index to assess the vegetation condition is the Normalized Difference Vegetation Index proposed by Rouse *et al.,* (1974). The NDVI has become the most commonly used vegetation index (Calvao and Palmeirim, 2004, Wallace *et al.,* 2004) and many efforts have been made aiming to develop further indices that can reduce the impact of the soil background and atmosphere on the results of spectral measurements. An example of a vegetation index limiting the influence of soil on remotely sensed vegetation data is SAVI (Soil Adjusted Vegetation Index) proposed by Huete (1988). The normalized difference vegetation index (NDVI), vegetation condition index (VCI), leaf area index (LAI), General Yield Unified Reference Index (GYURI), and Temperature Crop Index (TCI) are all examples of indices that have been used for mapping and monitoring drought and assessment of vegetation health and productivity (Doraiswamy *et al.,* 2003, Ferencz *et al.,* 2004, Prasad *et al.,* 2006). Kogan *et al.,* (2005) used vegetation indices from Advanced Very High Resolution Radiometer (AVHRR) data to model corn yield and early drought warning in China. Hadria *et al.,* (2006) provides an example of developing leaf area indices from four satellite scenarios to estimate distribution of yield and irrigated wheat in semi-arid areas. Examples of vegetation indices which are used specifically in agricultural purpose are listed in the table 1.

Crop condition assessment

Remote sensing can play an important role in agriculture by providing timely spectral information which can be used for assessing the Bio-physical indicators of plant health. The physiological changes that occur in a plant due to stress may change the spectral reflectance/ emission characteristics resulting in the detection of stress amenable to remote sensing techniques (Menon, 2012). Crop monitoring at regular intervals of crop growth is necessary to take appropriate measures and also to know the probable loss of production due to any stress factor. The crop growth stages and its development are influenced by a variety of factors such as available soil moisture, date of planting, air temperature, day length, and soil condition. These factors are responsible for the plant conditions and their productivity. For example, corn crop yields can be negatively impacted if temperatures are too high at the time of pollination. For this reason, knowing the temperature at the time of corn pollination could help forecasters better predict corn yields (Nellis *et al.,* 2009). The occurrence of drought also makes the land incapable for cultivation and renders inhospitable environment for human beings, livestock population, biomass potential and plant species (Siddiqui, 2004). The drought monitoring through satellite based information have been accepted in recent years and the use of Normalized Difference Vegetation Index (NDVI) and Vegetation Condition Index (VCI) have been accepted globally for identifying agricultural drought in different regions with varying ecological conditions (Nicholson and Farrar, 1994; Kogan, 1995; Seiler *et al.,* 2000; Wang *et al.,* 2001; Anyamba *et al.,* 2001; Ji and Peters, 2003). Crop growth and its condition are often characterized through the use of various vegetation indices such as reflectance ratio, NDVI, PVI, transformed vegetation index, and greenness index. Annual NDVI profiles are extracted in operational remote sensing for 12 Vegetation Phenology Metrics (VPMs), and these metrics are used to characterize agricultural vegetation response to varying climatic and land management practices (Reed *et al.,* 1994; Figure 2 and Table 2).

Nutrient and water status

The most important fields where we can opt for application of remote sensing and GIS through the application of precision farming are nutrient and water stress management. Detecting nutrient stresses by using remote sensing and GIS helps us in site specific nutrient management through which we can reduce the cost of cultivation as well as increase the fertilizer use efficiency for the crops. In semi-arid and arid regions judicious use of water can be made possible through the application of precision farming technologies. For example, drip irrigation coupled with information from remotely sensed data such as canopy air temperature difference can be used to increase the water use efficiency by reducing the runoff and percolation losses (Das and Singh, 1989). The spectral reflectance in the visible region was higher in water stressed crop than the non-stressed. The vegetation indices like NDVI, RVI, PVI and GI were found lower for stressed and higher for non-stressed crop. The advent of micro-wave remote sensing has made possible for estimating the soil moisture availability in the field. Information on crop water demand, water use, soil moisture condition, related crop growth at different stages can be obtained through the use of remote sensing data. Bandara (2003), for example, used NOAA satellite data to assess the performance of three large irrigation projects in Sri Lanka. Within this analysis, estimates using remote sensing of crop-water utilization were compared to actual water availability to determine irrigation efficiency. Das *et al*., (2018) developed a soil moisture and temperature map for India using high resolution land data assimilation system (HRLDAS) as a computing tool which is aimed at providing soil moisture and soil temperature at 1 km spatial resolution in near real-time (few hours' latency) at four soil depths and vegetation root zones. With the increase in the development of hyper spectral bands in the thermal region, remote sensing has been playing a major role in understanding the crop soil characteristics. Such information when linked with GPS will provide promising results which are more helpful in precision farming. Under the conditions of wet tropical and subtropical climates, the risk of nitrogen leaching is more due to spatial variability of soil properties, such as: SOM content (Casa *et al.,* 2011), water content (Delin and Berglund, 2005) and yield zones (Blackmore *et al.,* 2003; Bramley, 2009) which are having effects on the N nutrition status of corn plants in the field. This causes the failure of traditional single-rate N fertilization (TSF) which could over-fertilize some sites while other sites may be under-fertilized (Bredemeier and Schmidhalter, 2005). This promotes the use of variable-rate nitrogen fertilization (VRF) based on crop sensors which could increase the N fertilization efficiency (Singh *et al.,* 2006; Li *et al.,* 2010).

Crop evapo-transpiration

The decline in the productivity of crops is due to irregularities in rainfall, increase in the temperature rate etc., which causes a decrease in the soil moisture. Drought is a situation which can be defined as a long-term average condition of the balance between precipitation and evapo-transpiration in a particular area, which also depends on the timely onset of monsoon as well as its potency Wilhite and Glantz, (1985). In turn, vegetation indices such as CWSI (Crop Water Stress Index) (Jackson *et al.,* 1981), ST (Surface Temperature) (Jackson 1986), WDI (Water Deficit Index) (Moran *et al.,* 1994), and SI (Stress Index) (Vidal *et al.,* 1994) describe the relationship existing between water stress and thermal characteristics of plants. Sruthi *et al.,* (2015) analyzed the vegetation stress in the Raichur district of Karnataka by using the MODIS data for calculating NDVI values of the particular study area and its correlation with the land surface temperatures (LST). The LST when correlated with the vegetation index can be used to detect agricultural drought of a region and provides early warning systems to the farmers. Estimation of evapo-transpiration is essential for assessing the irrigation scheduling, water and energy balance computations, determining crop water stress index (CWSI), climatological and meteorological purposes. The energy emitted from cropped area has been useful in assessing the crop water stress as the temperature of the plants are mediated by the soil water availability and crop evapo-transpiration. Batra *et al.,* (2006) estimated evaporative fraction (EF), defined as the ratio of ET and available radiant energy, by successfully using AVHRR and MODIS data. Dutta *et al.,* (2015) used NOAA-AVHRR NDVI data for monitoring the spatio-temporal extent of agricultural drought in Rajasthan state. Neale *et al.,* (2005) provide an historical perspective on high resolution airborne remote sensing of crop coefficients for obtaining actual crop evapo-transpiration. Most of the approaches use simple direct correlations between remote sensed digital data and evapo-transpiration, but some combine various forms of remotely sensed data types. Remote sensing is playing a major role in the water management for agricultural system. And this can be further enhanced by the development of hyper spectral sensors and linking the remote sensing data with other spatial data through GIS and GPS technologies.

Weed identification and management

Precision weed management technique helps in carrying out the better weed management practices. Remote sensing coupled with precision agriculture is a promising technology in nowadays. Though, ground surveying methods for mapping site–specific information about weeds are very time–consuming and labor–intensive. However, image–based remote sensing has potential applications in weed detection for site–specific weed management (Johnson *et al.,* 1997; Moran *et al.,* 1997; Lamb *et al.,* 1999). Based on the difference in the spectral reflectance properties between weeds and crop, remote sensing technology provides a mean for identifying the weeds in the crop stand and further helps in the development of weed maps in the field so that site specific and need based herbicide can be applied for the management of weeds. Kaur *et al.,* (2013) reported higher radiance ratio and NDVI values in solid stand or pure wheat and minimum under solid weed plots. It was observed that by using radiance ratio and NDVI, pure wheat can be distinguished from pure populations of *Rumex spinosus* beyond 30 DAS. Different levels of Rumex populations could be discriminated amongst themselves from 60 DAS onwards. Kaur *et al.,* (2014) by using radiance ratio and NDVI, pure wheat can be distinguished from pure populations of *Malva neglecta* after 30 DAS and remain distinguished up to 120 DAS and different levels of weed population can be discriminated amongst themselves from 60 DAS onwards. Weed prescription maps can be prepared with Geographic Information System (GIS), on the basis of which farmers can be advised to take the preventive control measures.

Pest and disease infestation

Remote sensing has become an essential tool for monitoring and quantifying crop stress due to biotic and abiotic factors. Remote sensing methodologies need to be perfected for identification of insect breeding grounds for developing strategies to prevent their spread and taking effective control measures. The remote sensing approach in assessing and monitoring insect defoliation has been used to relate differences in spectral responses to chlorosis, yellowing of leaves and foliage reduction over a given time period assuming that these differences can be correlated, classified and interpreted (Franklin, 2001). The range of remote sensing applications has included detecting and mapping defoliation, characterization of pattern disturbances etc. and providing data to pest management decision support system (Lee *et al.,* 2010). William *et al.,* (1979) evaluated different types of vegetation indices on Landsat imagery acquired before and after defoliation to differentiate between healthy and unhealthy vegetation cover. De beurs and Townsend (2008) concluded that MODIS data represent an important tool for insect damaged defoliation and determination of vegetation indices in plot scale. Riedell *et al.,* (2004) reported remote sensing technology as an effective and inexpensive method to identify pest infested and diseased plants. They used remote sensing techniques to detect specific insect pests and to distinguish between insect and disease damage on oat. They suggested that canopy characteristics and spectral reflectance differences between insect infestation damage and disease infection damage can be measured in oat crop canopies by remote sensing. Mirik *et al.,* (2012) reported that the Landasat 5 TM image can be used to accurately detect and quantify disease for site-specific Wheat Streak Mosaic disease management in the wheat crop. Franke *et al.,* (2007) concluded that high resolution multi-spectral remote sensing data hold the potential for monitoring of fungal wheat diseases.

Crop yield and production forecasting

Remote sensing has been used to forecast crop yields primarily based upon statistical–empirical relationships between yield and vegetation indices (Thenkabail *et al.,* 2002, Casa and Jones 2005).The information on production of crops before the harvest is important for national food policy planning. Reliable crop yield is an important component of crop production forecasting purpose.

The crop yield is dependent on many factors such as crop variety, water and nutrient status of field, influence by weeds, pest and disease infestation, weather parameters. The spectral response curve is dependent on these factors. The growth and decay in the spectral response curve indicates the crop condition and its performance. By using IRS P3 WiFS (Wide Field Sensor) and IRS-1C WiFS and LISS3 which have a good periodicity, it may be possible to construct growth profiles and retrieve yield related parameters at region level (Menon, 2012).

Precision agriculture

Remote sensing technology is a key component of precision farming and is being used by an increasing number of scientists, engineers and large-scale crop growers (Liaghat and Balasundram, 2010).

Table.1 Some examples of vegetation indices having specific applications in agricultural sector. (Marek *et al.*, 2016)

Index	Formula & Spectral bands or wavelengths (nm)	Level/ sensor	Application	References
Advanced Normalised Vegetation Index	$ANVI = \frac{NIR - BLUE}{NIR + BLUE}$ **BLUE: 400-500** **NIR: 700-900**	Airborne (RMK TOP 15 camera)	Mapping Ridolfia segetum patches in sunflower crop	Pena-Barragan et al. (2006)
Aphid Index	$AI = \frac{NIR1 - NIR2}{RED1 + RED2}$ **RED1: 712** **RED2: 719** **NIR1: 761** **NIR2: 908**	Ground based (ASD FieldSpec3 spectrometer)	Identification of aphid infestation in mustard	Kumar et al. (2010)
Chlorophyll Index	$CI = \frac{NIR}{GREEN} - 1$ **GREEN: 520-600** **NIR: 760-900**	Groundbased (Exotech radiometrr) Satellite (QuickBird)	Plant nitrogen status estimates	Bausch and Khosla (2010)
Effective Leaf Area Index	$ELAI = -0.441 + 0.285\frac{NIR}{RED}$ **RED: 610-680** **NIR: 780-890**	Groundbased (CIMEL 313 radiometer)	Winter oilseed rape yield prediction	Wojtowicz *et al.*, (2005)
Green Normalised Difference Vegetation Index	$GNDVI = \frac{NIR - GREEN}{NIR + GREEN}$ **GREEN : 557-582** **NIR: 720-920 and/ or** **GREEN: 520-600** **NIR: 760-900**	Airborne (Multispectral Digital Camera)	Corn yield predictions	Chang *et al.*, (2003)
Green Red Vegetation Index	$GRVI = \frac{GREEN - RED}{GREEN + RED}$ **GREEN : 520-590** **RED: 620-680**	Groundbased (GER 1500 Spectroradio meter)	Estimation of Damage caused by thrips	Ranjitha *et al.*, (2014)
Healthy Index	$HI = \frac{GREEN - RED1}{GREEN + RED1} 0.5RED2$ **GREEN : 534**	Airborne (MCA-6 and Micro-Hyperspec	Early detection of Verticillium wilt of olive	Calderon *et al.*, (2013)

	RED1: 698 **RED2: 704**	Tetracam)		
Modified Soil Adjusted Vegetation Index	$MSAVI2 = 0.5[2NIR + 1 - \sqrt{(2NIR + 1)^2 - 8(NIR - RED)}$ **RED: 630-690** **NIR: 760-860**	Satellite (Terra ASTER)	Prediction of corn canopy nitrogen content	Bagheri *et al.,* (2012)
Normalised Difference Infrared Index	$NDII = \frac{NIR - SWIR}{NIR + SWIR}$ **NIR1: 845-885** **NIR2: 1650-170**	Airborne (MASTER)	Detection of Diurnal orchard canopy water content variation	Cheng *et al.,* (2013)
Normalised Difference Water Index	$NDWI = \frac{NIR1 - NIR2}{NIR1 + NIR2}$ **NIR1: 841-876** **NIR2: 1230-1250**	Satellite (MODIS)	Estimation of plant water content	Zarco-Tejada *et al.,* (2003)
Normalised Pigment Chlorophyll Ratio Index	$NPCI = \frac{RED1 - BLUE1}{RED2 + BLUE2}$ **BLUE: 460** **RED: 660**	Groundbased (Exotech and CropScan radio-meters)	Estimation of Leaf chlorophyll content	Hatfield And Prueger (2010)
Relative Reflectance Index	$RRI = \frac{NIR_a/VIS_a}{NIR_r/VIS_r}$ **VIS: 400-700** **NIR: 740-820**	Groundbased (quantum sensor LI-190s and LI-220S)	Indication of drought of field grown oilseed rape	Mogensen *et al.,* (1996)
Short wave Infrared Water Stress Index	$SIWSI(6,2) = \frac{SWIR - NIR1}{SWIR + NIR1}$ $SIWSI(6,2) = \frac{SWIR - NIR2}{SWIR + NIR2}$ **NIR1: 841-876** **NIR2: 1230-1250** **SWIR: 1628-1652**	Satellite (MODIS)	Indication of canopy water content	Fensholt and Sandholt (2003)
Triangular Greenness Index	TGI=-0.5[(RED-BLUE)(RED-GREEN)-(RED-GREEN)(RED-BLUE)] **BLUE: 450-520** **GREEN: 520-600** **RED: 630-690**	Ground based (ASD FieldSpec spectrometer), Airborne (AVIRIS), Satellite (Landsat TM)	Crop nitrogen requirements detection	Hunt *et al.,* (2013)

Table.2 Vegetation phenology metrics characterize vegetation phenology and are used to develop summary regional data for research on agro-ecosystem attributes (after Reed *et al.*, 1994)

Type	Metric	Interpretation
Temporal	1 Time of onset of greenness	Beginning of photosynthetic activity
	2 Time of end of greenness	End of photosynthetic activity
	3 Duration of greenness	Length of photosynthetic activity
	4 Time of maximum greenness	Time when photosynthesis at maximum
NDVI-value	5 Value of onset of greenness	Level of photosynthesis at start
	6 Value of end of greenness	Level of photosynthesis at end
	7 Value of maximum NDVI	Level of photosynthesis at maximum
	8 Range of NDVI	Range of measurable photosynthesis
Derived	9 Accumulated NDVI	Net Primary Production (NPP)
	10 Rate of green –up	Acceleration of increasing photosynthetic activity
	11Rate of senescence	Acceleration of decreasing photosynthetic activity
	12 Mean daily NDVI	Mean daily photosynthetic activity

Fig.1 Typical Spectral Reflectance curves for vegetation, dry bare soil and water

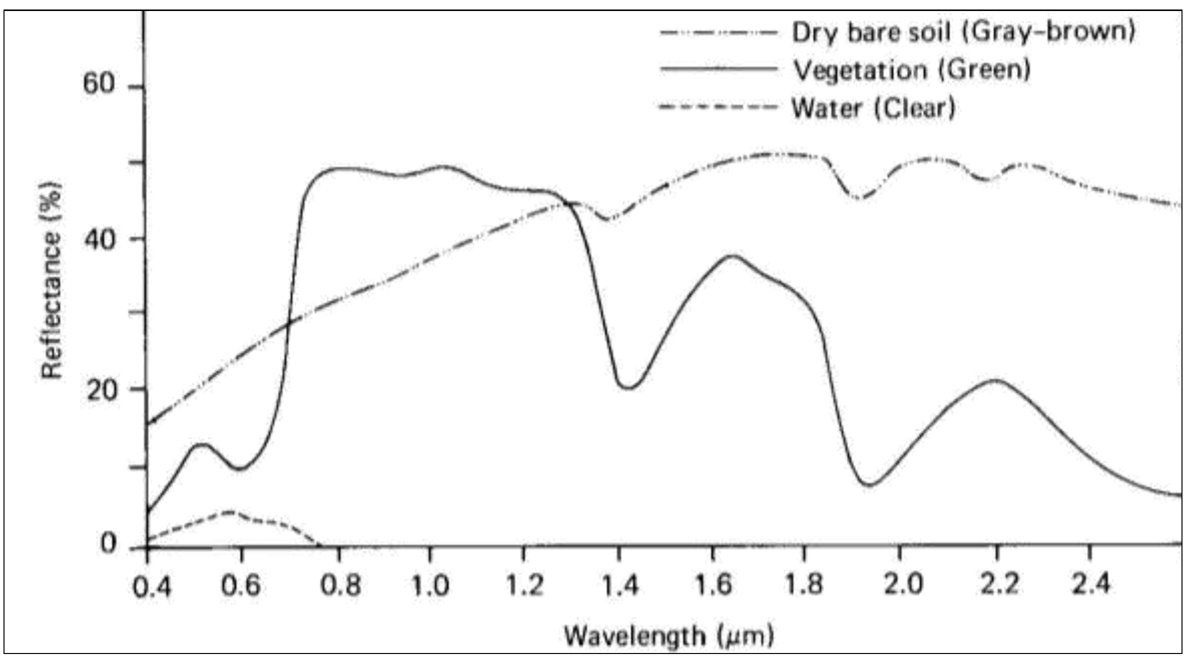
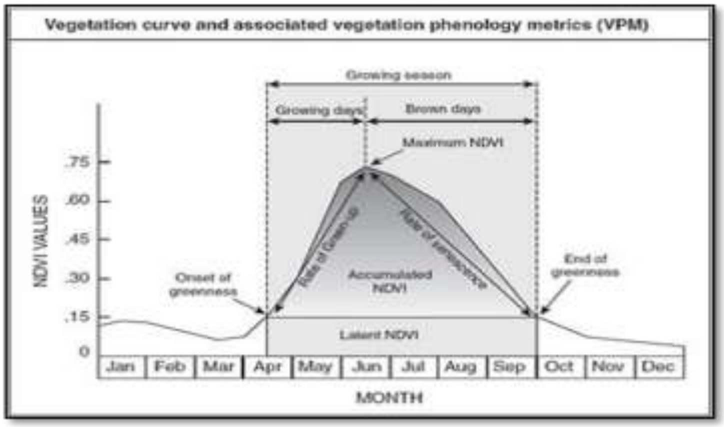


Fig.2 A twelve month, hypothetical NDVI temporal response curve for vegetation. Additionally, the vegetation metrics are displayed to show their relation to both NDVI values and time (after Reed *et al.*, 1994)



The main aim of precision farming is reduced cost of cultivation, improved control and improved resource use efficiency with the help of information received by the sensors fitted in the farm machineries. Variable rate technology (VRT) is the most advanced component of precision farming. Sensors are mounted on the moving farm machineries containing a computer which provides input recommendation maps and thereby controls the application of inputs based on the information received from GPS receiver (NRC, 1997). The advantage of precision farming is the acquisition of information on crops at temporal frequency and spatial resolution required for making management decisions. Remote sensing is a no doubt valuable tool for providing such informations. Bagheri *et al.*, (2013) used multispectral remote sensing for site‐ specific nitrogen fertilizer management. Satellite imagery from the advanced spaceborne thermal emission and reflection radiometer (Aster) was acquired in a 23 ha corn‐ planted area in Iran.

Atmospheric dynamics

Among the other applications through remote sensing, meteorological satellites are playing an important role in the forecasting of weather conditions. Meteorological satellites are designed to measure the atmospheric temperature, wind, moisture and cloud cover. The variations in the canopy temperature could indicate the areas of adequate and inadequate water in the field condition. The canopy temperature variability (CTV) is used in irrigation management and canopy air temperature difference (CATD) might be used as an indicator of crop water stress (Menon, 2012). Drought assessment playing a major role in the field of agriculture, wherein remote sensing data has been used for taking management decisions. The district level drought assessment and monitoring using NDVI generated from NOAA-AVHRR data helps in taking timely preventive and corrective measures for combating drought.

Future prospects

Remote sensing is highly useful in assessing various abiotic and biotic stresses in different crop and also very useful in detecting and management of various crop issues even at small farm holdings. To effectively utilize the information on crops for improvement of economy there is a need to develop state or district level information system based on available information on various crops derived from remote sensing and GIS approaches. The governments can use remote sensing data in order to make important decisions about the policies they will adopt or how to tackle national issues regarding agriculture. A new and nontraditional remote sensing application involves the implanting of nano-chips in plant and seed tissue that can be used in near-real time to monitor crop. Clearly, these and other new approaches will reinforce the importance of remote sensing in future analysis of agricultural sciences.

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