Chapter

Remote Sensing for Agricultural Applications

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Abstract

The application of remote sensing in quantifying the crop health status is trending. Sensors can serve as early warning systems for countering climatic or biological aberrations before having negative impacts on crop yield. Remote sensing applications have been playing a significant role in agriculture sector for evaluating plant health, yield and crop loss (%) estimation, irrigation management, identification of crop stress, weed and pest detection, weather forecasting, gathering crop phenological informations etc. Forecast of crop yields by using remote sensing inputs in conjunction with crop simulation models is getting popular day by day for its potential benefits. Remote sensing reduces the amount of field data collection and improves the precision of the estimates. Crop stress caused by biotic and abiotic factors can be monitored and quantified with remote sensing. Monitoring of vegetation cover for acreage estimation, mapping and monitoring drought condition and maintenance of vegetation health, assessment of crop condition under stress prone environment, checking of nutrient and moisture status of field, measurement of crop evapotranspiration, weed management through precision agriculture, gathering and transferring predictions of atmospheric dynamics through different observational satellites are the major agricultural applications of remote sensing technologies. Normalized difference vegetation index (NDVI), vegetation condition index (VCI), leaf area index (LAI), and General Yield Unified Reference Index (GYURI) are some of the indices which have been used for mapping and monitoring drought and assessing vegetation health and productivity. Remote sensing with other advanced technologies like geographical information systems (GIS) are playing a massive role in assessment and management of several agricultural activities. State or district level information systems based on available remote sensing information are required to be utilized efficiently for improving the economy coming from agriculture.

Keywords: remote sensing, agriculture, vegetation indices, yield forecast

1. Introduction

In remote sensing, objects or areas of the real world are studied by gathering information at a distance without physical contact. In addition to ground

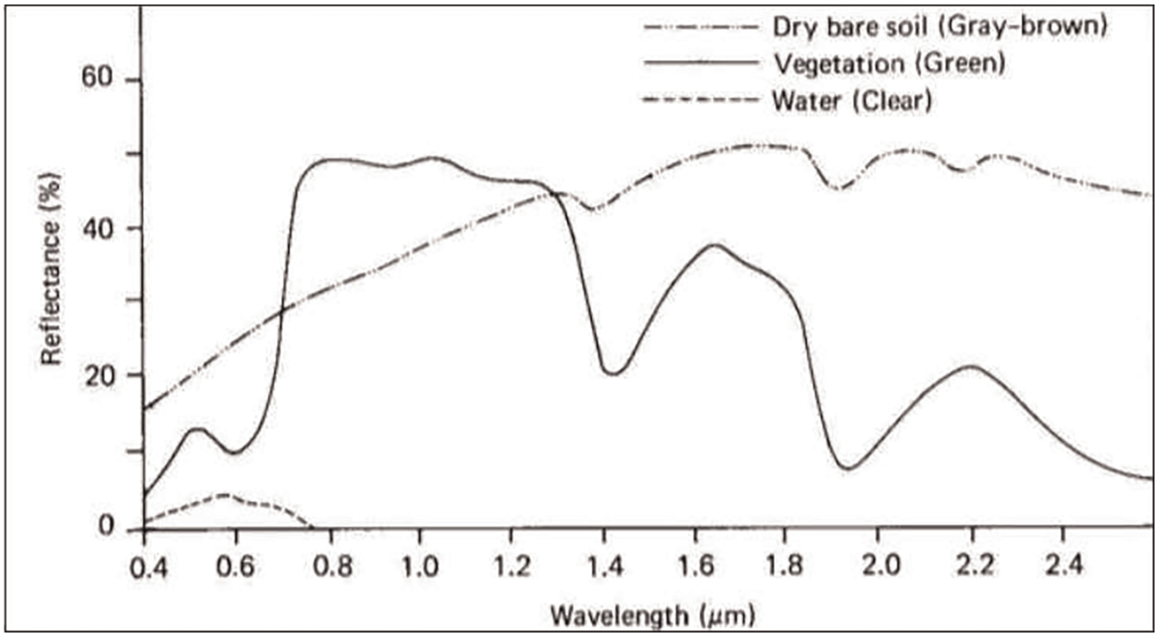

Figure 1.
Typical spectral reflectance curves for vegetation, dry bare soil and water.

observations, remote sensing uses non-contact technologies to monitor the earth's resources. The spectral characteristics of different objects are unique in nature and can be utilized to derive information such as temperature, water content etc. The use of visible, infrared and microwaves to evaluate any physical features has been well established. It is used to distinguish vegetation from bare soil, water, and other similar features based on the responses of the targets to these wavelength regions (see **Figure 1**). Also, it can be used in monitoring crop growth, land use pattern and land cover changes, mapping of water resources and monitoring of water status, weather forecasting and crop yield estimation, and monitoring diseases and pest infestations. Thus the application of remote sensing data in agriculture can provide a timely, efficient, and cost efficient approach [1]. Several agrometeorological applications are also possible. It is very useful to forecast crop yields by using remote sensing inputs in conjunction with crop simulation models. For complementing traditional meteorological and crop status data collection methods, the space based satellite technology is becoming increasingly important, since ground and air-based platforms are time consuming and limited in their use.

2. Agricultural applications

Satellite remote sensing began with most researchers using data for land cover classification, with farmers focusing on crop types as a major application. Plant biophysical properties have become more important in agricultural remote sensing in recent years. The use of remote sensing in agriculture has been around for a long time. The classification of crop canopies based on image processing is one the biggest milestone achieved in this field. In precision agriculture, remote sensing offers the advantage of providing repeated information without destructive sampling of crops, which can provide useful information. In large geographic areas, remote sensing provides an inexpensive alternative to traditional data collection methods [2]. Agriculture crop acreage and production are mainly estimated by satellite remote sensing in India. Based on biophysical attributes of crops and/or soils, remote sensing technology has the potential to revolutionize agricultural productivity detection and characterization [3]. Using satellite data, yield estimation can be done [4, 5], crop phenological information can be gathered [6], stress situations can be identified [7] and disturbances can also be detected. As a result of the combined use of remote sensing and GIS, spatial variables of interest can be created that can be applied to a variety of fields, including flood plain mapping, hydrological modeling, surface energy flux, urban development, land use changes, crop growth monitoring, and stress detection [8]. Increasing spatial resolution of aircraft or satellite mounted sensors has led to advances in remote sensing methods that use narrow band or hyperspectral sensors. A more detailed analysis of crop classification has also been enhanced by hyperspectral remote sensing. Using a combination of principal component analysis, lambda-lambda models, stepwise discriminant analyses, and a derivative greenness vegetation index, Thenkabail et al. [9] conducted rigorous analysis on hyperspectral sensors (between 400 and 2500 nm) in order to determine whether there had been any change in crop composition. There have been many investigation procedures using sensors which can provide reliable data in a timely manner at a fraction of the cost of traditional data gathering methods.

3. Monitoring of vegetation cover

Agricultural acreage estimation and yield assessment rely heavily on the science of remote sensing. Researchers used aerial photographs as well as digital image processing techniques to conduct a number of experiments. However, remote sensing reduces the amount of field data collected and improves the precision of estimates [8]. A significant improvement in crop characterization, discrimination, modeling, and mapping is known to be possible with hyperspectral data, compared with broadband multispectral remote sensing [10]. Using 33 optimal HNBs and an equal number of two-band normalized difference HVIs, Thenkabail et al. [10] characterized, categorized, mapped, and studied biophysical and biochemical quantities of major agricultural crops. Remote sensing techniques are generally used to assess the crop's health and yield based on physical parameters such as nutrient stress and water availability. The spectral characteristics of any vegetation depends on various factors such as water content, cell density, elemental concentration etc. This feature is used to extract numerous information of a sample field from different type of spectral band. Remote sensing indices are being used by other researchers to provide synoptic perspectives on regional crop conditions. Rouse et al. [11] proposed the Normalized Difference Vegetation Index as a way to assess vegetation condition [11]. There has been a great deal of effort made to develop additional vegetation indices that reduce the influence of soil background and atmosphere on spectral measurements, as the NDVI has become the most widely used vegetation index [12, 13]. Remotely sensed vegetation data can be managed with SAVI (Soil Adjusted Vegetation Index), an index developed by Huete [14]. A number of indices have been used for mapping and monitoring drought and assessing vegetation health and productivity, including the normalized difference vegetation index (NDVI), vegetation condition index (VCI), leaf area index (LAI), and General Yield Unified Reference Index (GYURI) [4, 15, 16]. A very high resolution radiometer (AVHRR) data was used by Kogan et al. [17] to model corn yield and early drought warning in China using vegetation indices from Advanced Very High Resolution Radiometer (AVHRR) data. A semi-arid region yield and

Index	Formula and spectral bands or wavelengths (nm)	Level/sensor	Application
Advanced normalized vegetation	$\mathrm{ANVI} = \frac{\mathrm{NIR}-\mathrm{BLUE}}{\mathrm{NIR}+\mathrm{BLUE}}$	Airborne(RMKTOP 15camera)	Mapping Rodolfo segetum
Index	**BLUE:400–500** **NIR: 700–900**		Patches in sunflower crop
Aphid Index		Ground based (ASD FieldSpec3spectrometer)	Identification of aphid infestation in mustard
	RED1:712 RED2:719		
	NIR1:761 NIR2:908		
Chlorophyll	$\mathrm{CI} = \frac{\mathrm{NIR}}{\mathrm{GREEN}} - 1$	Ground based	Plant nitrogen
Index	**GREEN:520–600** **NIR: 760–900**	(Exotic radiometer)Satellite (Quick Bird)	Status estimates
Effective	$\mathrm{ELAI} = -0.441 + 0.285\frac{\mathrm{NIR}}{\mathrm{RED}}$	Ground based	Winter oilseed
Leaf Area Index		(CIMEL313 radiometer)	rape yield prediction
	RED:610–680		
	NIR: 780–890		
Green	$\mathrm{GNDV1} = \frac{\mathrm{NIR}-\mathrm{GREEN}}{\mathrm{NIR}+\mathrm{GREEN}}$		
Normalized	**GREEN:557–582** **NIR: 720–920 and/or** **GREEN:520–600** **NIR: 760–900**	Airborne	Corn yield
Difference		(Multispectral	predictions
Vegetation		Digital	
Index		Camera)	
Green Red	$\mathrm{GRV1} = \frac{\mathrm{GREEN}-\mathrm{RED}}{\mathrm{GREEN}+\mathrm{RED}}$	Ground based	Estimation of
Vegetation Index	**GREEN:520–590**	(GER1500 Spectro radiometer)	Damage caused by thrips
	RED:620–680		
Healthy	$\mathrm{HI} = \frac{\mathrm{GREEN}-\mathrm{RED1}}{\mathrm{GREEN}+\mathrm{RED1}} 0.5\mathrm{RED2}$	Airborne	Early
Index	**GREEN:534**	(MCA-6 and Micro-Hyper spec	detection of Verticillium wilt of olive

Table 1.
Some examples of vegetation indices having specific applications in agricultural sector.

irrigated wheat distribution is estimated using leaf area indices from four satellite scenarios [18]. As shown in **Table 1**, there are some vegetation indices that can be used specifically for agricultural purposes.

4. Crop condition assessment

The use of remote sensing to assess plant health through spectral information can be beneficial in agriculture. It is possible to detect stress in plants by using remote sensing techniques due to physiological changes caused by stress [19]. Monitor crop growth at regular intervals in order to take appropriate actions and also to determine whether any stress factor is likely to affect production. A variety of factors contribute

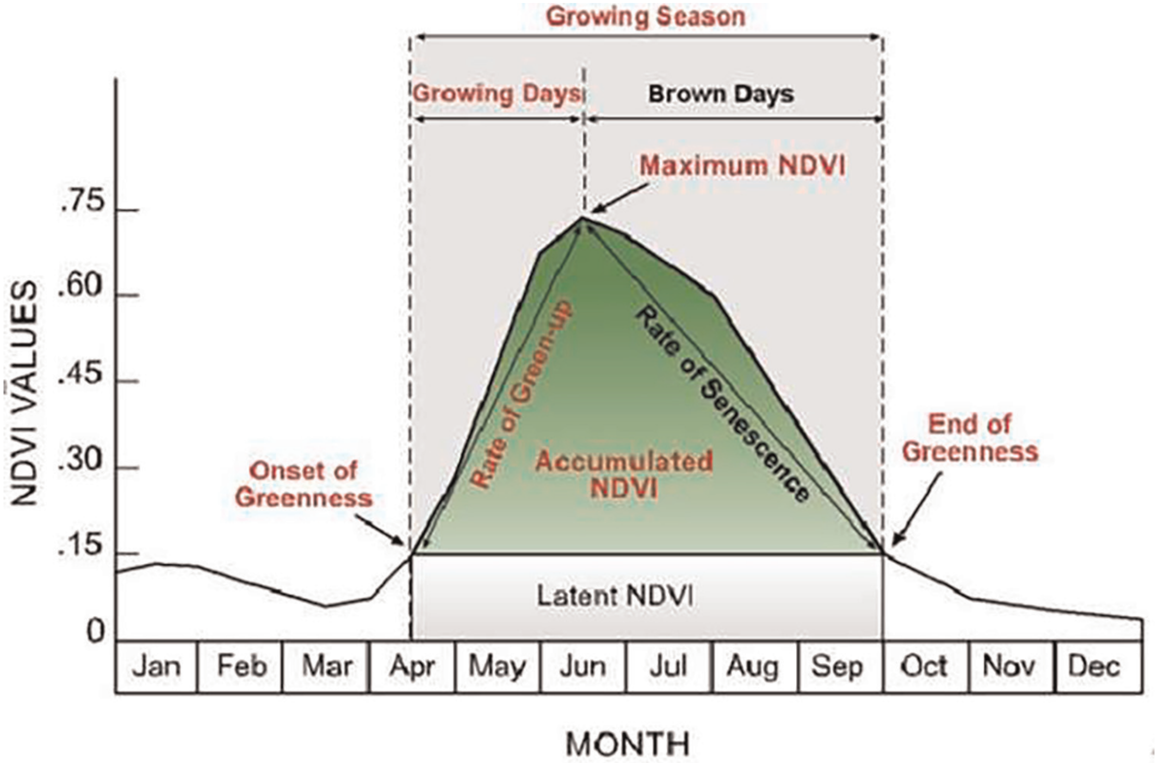

Figure 2.
A diagram of a hypothetical 12-month NDVI multi-temporal vegetation response curve for native vegetation that is typical of the Great Plains region, USA. Shown on the graph are selected vegetation phenology metrics that can be extracted through the analysis of the NDVI, near cloud-free datasets (adopted from Reed et al. [22]).

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
	11. Rate of senescence	Acceleration of decreasing photosynthetic activity
	12. Mean daily NDVI	Mean daily photosynthetic activity

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. [22]).

to the growth stages and development of crops, including soil moisture, date of planting, air temperature, and day length. The conditions and productivity of plants are influenced by these factors. Too high temperatures at pollination, for example, can negatively impact corn crop yields. Forecasters may be able to better predict corn yields if they know the temperature when pollination occurs [20]. Siddiqui [21] explains that drought makes land inhospitable to humans, livestock, biomass potentials, and plant species, and also causes the land to be incapable of cultivation. Drought monitoring through satellite data has been widely accepted now and the Vegetation Condition Index (VCI) and Normalized Difference Vegetation Index (NDVI) are widely used to identify agricultural drought in regions with different ecological conditions. Many vegetation indices are used to measure crop growth and condition, such as reflectance ratios, NDVIs, PVIs, transformed vegetation indexes, and greenness indices. With operational remote sensing, NDVI profiles are extracted each year for 12 Vegetation Phenology Metrics (VPMs), and these metrics are used to analyze agricultural vegetation changes due to changes in climate and land management practices (**Figure 2** and **Table 2**) [22].

5. Nutrient and water status

Through precision farming, remote sensing and GIS can be applied to nutrient and water stress management, which are the most important fields. Utilizing remote sensing and GIS to detect nutrient stress can help us reduce cultivation costs and increase fertilizer efficiency for crops through site-specific nutrient management. Precision farming technologies can be used to judiciously use water in semi-arid and arid regions. Das and Singh [23] demonstrated that drip irrigation combined with remote sensing data can improve the efficiency of water use by reducing runoff and percolation losses. In the visible region, water stressed crops displayed higher spectral reflectance than non-stressed crops. There was a difference between stressed and non-stressed crops in terms of vegetation indices like NDVI, RVI, PVI, and GI. In the field, soil moisture can be estimated using microwave remote sensing. Through remote sensing data, it is possible to obtain information on crop water demand, water use, soil moisture conditions, and related crop growth at various stages. Sri Lankan irrigation projects were assessed using NOAA satellite data by Bandara [24], for example. In this analysis, irrigation efficiency was determined by comparing estimates from remote sensing with actual water availability. Based on high resolution land data assimilation system (HRLDAS), Das et al. [25] developed a soil moisture and temperature map for India with a spatial resolution of 1 km, in near real-time (with a few hours' latency) for four soil depths and vegetation root zones. Remote sensing has played an important role in understanding crop soil characteristics with the development of hyperspectral bands in the thermal region. Precision farming can be more effective with such information provided in conjunction with GPS. It has been demonstrated that nitrogen leaching occurs more often in wet tropical and subtropical climates due to spatial variability of soil properties, such as SOM content [26], water content [27] and yield zones [28, 29]; these properties are having a direct impact on the N nutrition status of corn plants. Bredemeier and Schmidhalter [30] indicate that this results in the overfertilization of some sites and the under fertilization of others. By using crop sensors [31, 32], we are able to increase nitrogen fertilization efficiency with variable-rate nitrogen fertilization (VRF).

6. Crop evapo-transpiration

Increasing temperatures and irregular rainfall cause a decrease in soil moisture, which in turn decreases crop productivity. It is defined as a situation in which precipitation and evapo-transpiration are balanced over the long-term average, which is also affected by the timing and potency of the monsoon [33]. The relationship between water stress and a plant's thermal characteristics is described by vegetation indices such as CWSI (Crop Water Stress Index) [34], ST (Surface Temperature) [35], WDI (Water Deficit Index) [36], and SI (Stress Index) [37]. Based on MODIS data, Sruthi et al. [38] calculated NDVI values and correlated them with land surface temperatures for the Raichur district of Karnataka. In conjunction with the vegetation index, the LST provides early warning systems to farmers if a region is experiencing an agricultural drought. Evapo-transpiration estimates are essential for evaluating irrigation scheduling, calculating water and energy balances, determining crop water stress indexes (CWSIs), and determining climatological and meteorological conditions. As soil water availability and crop evapo-transpiration are directly related to plant temperature, the energy emitted by cropped areas has been useful in assessing crop water stress. The AVHRR and MODIS data can be used in estimating evaporative fraction (EF) demonstrated by Batra et al. [39]. The spatio-temporal extent of agricultural drought in Rajasthan state was monitored using NOAA-AVHRR NDVI data by Dutta et al. [40]. Using airborne remote sensing to measure crop evapotranspiration, Neale et al. [41] provide an overview of crop coefficients obtained from high resolution airborne remote sensing. There are various approaches to calculating evapo-transpiration from remote sensed data; most use simple correlations between remote sensed data and evapo-transpiration, but some combine different types of remotely sensed data. Water management for agricultural systems relies heavily on remote sensing. By developing hyperspectral sensors and integrating the remote sensing data with other spatial data, this can be further enhanced.

7. Weed identification and management

In order to manage weeds effectively, precision weed management techniques are helpful. Precision agriculture combined with remote sensing is today's most promising technology. Although ground surveying for mapping weeds is very labour intensive and time-consuming, it is a good method for mapping weed information for a specific location. Image-based remote sensing can be utilized for weed detection and site-specific weed management [36, 42, 43]. Using remote sensing technology to identify weeds in crops and to develop weed maps in the field can allow site specific and need-based herbicides to be applied to manage weeds based on the difference in spectral reflectance properties between weeds and crops. The radiance ratio and the NDVI values of solid stands of wheat and solid weed plots were higher in Kaur et al. [44]. Beyond 30 days, radiance ratios and NDVI can be used to distinguish pure wheat from pure *Rumex spinosus* populations. Rumex populations at different levels could be discriminated between themselves after 60 DAS. The radiance ratio and NDVI were used by Kaur and Jaidka [45] to distinguish pure wheat from pure populations of *Malva neglecta* after 30 days after planting and to remain distinct up to 120 days later, and to discriminate between different levels of weed populations after 60 days of planting. Farmers can be advised to take preventive measures based on weed prescription maps that can be prepared with Geographic Information System (GIS).

8. Pest and disease infestation

Crop stress caused by biotic and abiotic factors can be monitored and quantified with remote sensing. To prevent the spread of insects and take effective control measures, remote sensing methodologies need to be perfected for identifying insect breeding grounds. Using remote sensing to assess and monitor insect defoliation, spectral response to chlorosis, yellowing leaves, and foliage reductions over a given period of time has been used to relate those differences' correlations, classifications, and interpretations [46]. Lee et al. [47], for example, have applied remote sensing to map and detect defoliation, characterize pest destruction pattern, and provide information to pest management decision support systems. The authors of William et al. [48] analyzed Landsat imagery before and after defoliation to determine which vegetation types were healthy and unhealthy. A study conducted by Debeurs and Townsend [2] concluded that MODIS data could be used for estimating vegetation indices in plots and determining insect-damaged defoliation. Using remote sensing technology to identify pest-infested and diseased plants has proven to be an effective and inexpensive method reported by Riedell et al. [49]. For detecting specific insect pests and identifying disease damage on oat, they used remote sensing techniques. It is suggested that remote sensing can be used to measure canopy characteristics and spectral reflectance differences in oat crop canopies in order to assess insect infestation damage and disease infection damage. Wheat Streak Mosaic disease management in the wheat crop can be supported by accurate detection and quantification of disease using the Landasat 5TM image, according to Mirik et al. [50]. Using multispectral remote sensing, Franke and Menz [51] concluded that fungal wheat diseases can be monitored with high resolution.

9. Crop yield and production forecasting

Various statistical-empirical relationships between yield and vegetation indices have been used in remote sensing to forecast crop yields [52, 53]. Information on crop production before harvest is essential for national food policy planning. Forecasting crop production requires reliable crop yields. A number of factors influence crop yield, including crop variety, water and nutrient status of a field, weed infestations, pest and disease infestations, and weather parameters. It is dependent on these factors that the spectral response curve appears. Spectral response curves indicate the crop's performance and condition based on their growth and decay. Menon [19] suggests that growth profiles can be constructed and yield related parameters can be extracted by using IRS P3 WiFS (Wide Field Sensor) and IRS-1C WiFS.

10. Precision agriculture

As scientists, engineers and large-scale crop growers increasingly use remote sensing technology for precision farming [3], it is becoming a key component of the same. With the help of the sensors fitted in farm machines, precision farming aims to reduce the cost of cultivation, improve control, and improve resource utilization efficiency. One of the most advanced components of precision farming is variable rate technology (VRT). The moving farm machines contain sensors with a computer that recommends inputs based on GPS data. This allows the application of inputs to be controlled based on input recommendation maps [54]. Using precision farming, you can make management decisions based on information acquired at frequent intervals and at high spatial resolutions. In order to provide such information, remote sensing is undoubtedly an important tool. Multispectral remote sensing was used by Bagheri et al. [55] to manage nitrogen fertilizer at specific sites. An Iranian corn-planting area measuring 23 ha was imaged with the advanced spaceborne thermal emission and reflection radiometer (ASTER).

11. Atmospheric dynamics

The use of meteorological satellites in weather forecasting is one of the other applications of remote sensing. Cloud cover, wind, moisture, temperature, and wind speed are measured by meteorological satellites. It may be possible to determine whether there is enough or inadequate water in the field based on variations in canopy temperature. It is possible to use canopy temperature variability (CTV) to monitor crop water stress [19] as well as canopy air temperature difference (CATD) to determine if the canopy is overwatered [19]. The use of remote sensing data for drought assessment plays a significant role in agriculture. NDVI produced by NOAA-AVHRR data is used to assess and monitor droughts at the district level, allowing timely preventive and corrective measures to be taken.

12. Future prospects

Even at small farms, remote sensing is highly useful in detecting and managing various crop problems, including abiotic and biotic stresses. State or district level information systems based on available remote sensing and GIS crop information are required to efficiently utilize the information on crops for improving the economy. In order to adopt policies or address national issues related to agriculture, governments can make use of remote sensing data. Plant and seed tissue nano-chips can be implanted in near-real time to monitor crops using a new and non-traditional remote sensing technique. In the future, remote sensing will clearly play a more important role in assessing agricultural science.

13. Conclusion

The resolution of the satellite images (MODIS- minimum resolution 250 m, LANDSAT- minimum resolution 15 m) are the key constraints in this field. Agricultural fields are so much versatile in nature with respect to moisture content, topography, elevation, nutrient content that the empirical relationship established between source to sink is highly vulnerable. Standardized relationship between the crop spectral characteristics and physio-chemical properties needs to be established crop specifically. The initial installation cost of a satellite is till now very high and out of scope for an individual. The lone application of remote sensing in precision agriculture may lead to confusion and wastage of resources so the importance of ground truthing still remain pertinent. This makes the application of satellite derived remotely sensed data quite complicated and costly for the policy makers. The recent advancement in high resolution field level image processing obtained through drones compiled with the satellite derived knowledge is quite promising. Though the remote sensing applications have a lot of theoretical consideration and backdrops, it has a huge scope in agricultural sciences to serve the humanity with higher production, vulnerability prediction and impact assessment under the context of rapid climate change.

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Conflict of interest

The authors declare no conflict of interest.

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