Applications of Remote Sensing in Horticulture

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Abstract

Horticulture crops play significant role in improving the productivity of land, generating employment, enhancing exports, improving economic conditions of the farmers and entrepreneurs and providing food and nutritional security to the people. For better management of the existing crops and to bring more area under horticulture crops, updated and accurate database is necessary for systematic planning and decision making. Remote sensing (RS) is an advanced tool that aids in gathering and updating information to develop scientific management plans. Many types of sensors namely microwave radiometers, laser meters, magnetic sensors and cameras collect electromagnetic information to derive accurate, large-scale information about the Earth's surface and atmosphere. Because these data and images are digital, they can easily be quantified and manipulated using computers. RS can be used in efforts to reduce the risk and minimize damage. The same data can be analyzed in different ways for different applications. A number of studies were aiming at identification of crop, area estimation, disease and pest identification, etc. using satellite data in horticulture. The potential use of RS techniques in Horticulture is briefly reviewed in order to exploit the available techniques for efficient crop management.

Introduction

Horticulture crops comprising of fruits, vegetables, flowers, spices, plantation crops and medicinal plants play a significant role in economy, employment, national self-reliance, health, food and nutritional security of the country. During the past few years, horticulture development has emerged as one of the major thrust area in agriculture sector. For optimum utilization of available horticultural land resources on a sustainable basis, timely and reliable information regarding their nature, extent and spatial distribution along with their potential and limitations is very important. The key factors that contribute towards crop growth and production are different soil characteristics (soil pH, nutrient levels, drainage efficiency, texture, permeability and water holding capacity), climatic conditions (temperature, rainfall, solar radiation, chilling hours, growing degree days) and land-use type (soil properties, topography), plant population, fertilization, irrigation, and pest infestations. All these physical factors must be part of a geospatial database (Schumann and Zaman, 2003, Panda et al., 2011). RS systems due to regular, synoptic, multispectral and multi temporal coverage of an area provide accurate database on spectral behaviour of crops as well as their growing environment, i.e. soil and atmosphere. They can be used for a number of applications like crop inventory, crop condition, crop production forecasts, fruit quality, leaf area index, crown cover, for detection of the growth and health of horticultural crops, drought and flood damage assessment, range and irrigated land monitoring and management (Min et al., 2008a, Mondal and Basu, 2009). The delineation of orchards and spatial analysis using geospatial technology can provide additional information for management and decision making for successful application of site-specific crop management (SSCM), determination of fruit yield, quantification and scheduling of precise and proper fertilizer, irrigation needs, application of pesticides for pest and disease management and has potential for increasing net returns and optimizing resource (Ray et al., 2006, Panda and Hoogenboom, 2009). High-resolution multispectral satellite imagery was used to develop viticulture decision support products related to monitoring of field uniformity, vine balance, and irrigation planning (Johnson et al., 2003). Crop yield is perhaps the most important piece of information for crop management in precision agriculture. Despite the commercial availability and increased use of yield monitors, most of the harvesters are not equipped with them. Moreover, yield monitor data can only be used for after-season management, whereas some problems such as nutrient deficiencies, water stress, or pest infestations should be managed during the growing season. RS imagery obtained during the growing season has the potential not only for after-season management, but also for within-season management. Additionally, yield maps derived from RS imagery can be used as an alternative when yield monitor data are not available (Li et al., 2010).

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 plays 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.

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 microwave 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 purepopulations 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 multispectral 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). 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 non-traditional 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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