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Applications of remote sensing and GIS in fruit crops: A review

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Abstract
Fruit crops play crucial role in enhancing the land productivity, employment generation, escalating exports, upgrading economic conditions of the farmers and entrepreneurs and bestowing food and nutritional security to the people. For effective management of the prevailing crops and to extend the area under fruit crops, upgraded and reliable database is required for systematic planning and decision making. Remote sensing (RS) is a progressive tool which assists in assembling and updating information to augment scientific management strategies in fruit crops. Now-a-days the discipline of Remote Sensing and Geographical Information System (GIS) has become inspiring and beneficial with swiftly widening opportunities and supplies crucial tools that can be applied at numerous levels leading to decision making towards sustainable socio-economic development and preservation of natural resources. Remote sensing and GIS technology, and its implementation in fruit crops, have sustained a successful development in recent decades. GIS and remote sensing can play a major role in the rapid planning of several control management programmes. Moreover, remote sensing and GIS have been utilised conjunctively in diverse studies for addressing issues associated to developmental planning. Remote sensing also supplies a sound data base for creating baseline information on natural resources, a pre-requisite for planning and implementation, and monitoring of any developmental programme.

Keywords: remote sensing, GIS, fruit crops, radiation

Introduction
A slow evolution of information technologies has been seen in production of fruit crops as innovators incorporated their previous field experience with an attitude of learning by doing while looking for practical applications for farm management. The significance of satellite or aerial imaging, along with Geographical Information System (GIS) and Global Polar Satellite (GPS), is the initial step towards the successful implementation of Site-Specific Crop Management (SSCM) in fruit crops. Multiplication in the net returns and optimization of resource use in horticultural crops, especially the fruit crops can be achieved with the utilization of Site-Specific Crop Management (SSCM). The orchards delineation and spatial analysis employing geospatial technology can impart subsidiary information for management decision making, such as fruit yield determination, the quantification and scheduling of precise and proper fertilizer, irrigation requirements and pesticide application for pest and disease management.

Remote Sensing
Remote sensing is the science and art of acquiring information about an object, area, or phenomena through the analysis of data obtained by a device that is not in contact with the target under investigation. Or it may be defined as the process of obtaining information about land, water or an object without any physical contact between the sensor and the subject under observation (Remote – Not in contact with an object and Sensing – Getting information). Or it is the assessment or acquisition of information of some property of an object or phenomena by a recording device that is not in physical or intimate contact with the object or phenomena under study. Remote sensing is a multidisciplinary approach which comprises of different sciences such as, optics, spectroscopy, computer, satellite launching, photography and electronics. Basic knowledge of all these science is very essential and it is being exploited in applications of remote sensing.

Fundaments of remote sensing

Process of remote sensing

Remote sensing procedure involves an interaction between incident radiation and the targets of interest. This is exemplified by the use of imaging systems where the following seven elements are involved (fig.1)

1. **Energy Source or Illumination (A):** The first necessity for remote sensing is to have an energy source which illuminates or provides electromagnetic energy to the target of interest.
2. **Radiation and the Atmosphere (B):** As the energy travels from its source to the target, it comes in contact with and interacts with the atmosphere it passes through. This interaction takes place a second time as the energy travels from the target to the sensor.
3. **Interaction with the Target (C):** Once the energy makes its way to the target through the atmosphere, it interacts with the target depending on the properties of both the target and the radiation.
4. **Recording of Energy by the Sensor (D):** After the energy has been scattered by, or emitted from the target, a device known as sensor (remote - not in contact with the target) collects and records the electromagnetic radiation
5. **Transmission, Reception and Processing (E):** The energy recorded by the sensor is transmitted, often in electronic form, to a receiving and processing station where the data are processed into an image (hardcopy and/or digital).
6. **Interpretation and Analysis (F):** The processed image is interpreted, visually and/or digitally or electronically, to extract information about the target which was illuminated.
7. **Application (G):** The final element of the remote sensing process is achieved when we apply the information we have been able to extract from the imagery about the target in order to better understand it, reveal some new information, or assist in solving a particular problem.

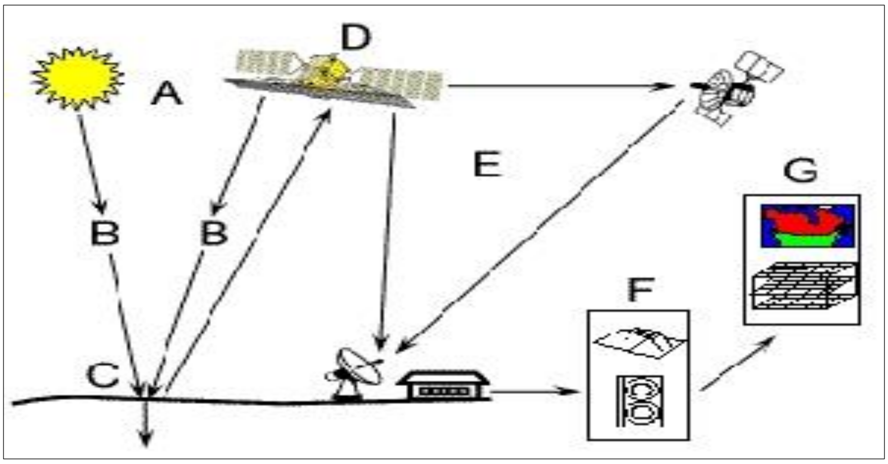

Fig 1: Process of Remote Sensing

Electromagnetic radiation

The first requirement for remote sensing is to have an energy source to illuminate the target (unless the sensed energy is being emitted by the target). This energy is in the form of electromagnetic radiation. All electromagnetic radiation has fundamental properties and behaves in predictable ways according to the basics of wave theory.

Electromagnetic radiation consists of an electrical field(E) which varies in magnitude in a direction perpendicular to the direction in which the radiation is traveling, and a magnetic field (M) oriented at right angles to the electrical field. Both these fields travel at the speed of light (c). Two characteristics of electromagnetic radiation are particularly important for understanding remote sensing. These are the wavelength and frequency.

The wavelength is expressed as the length of one wave cycle, which is measured as the distance between successive wave crests. Wavelength is usually represented by the Greek letter lambda (λ). Wavelength is measured in metres (m) or some factor of metres. Frequency refers to the number of cycles of a wave passing a fixed point per unit of time. Frequency is normally measured in hertz (Hz).

Electromagnetic spectrum

The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves) (fig.2). The several regions of the electromagnetic spectrum useful for remote sensing are as follows:

1. **Ultraviolet or UV spectrum:** This portion of the spectrum consists of the shortest wavelengths which are practical for remote sensing. This radiation is beyond the violet portion of the visible wavelengths. Some Earth surface materials, primarily rocks and minerals, fluoresce or emit visible light when illuminated by UV radiation.
2. **Visible spectrum:** The light which our eyes can detect is part of the visible spectrum. The visible wavelengths cover a range from 0.4 to 0.7 µm. The longest visible wavelength is red and the shortest is violet.
3. **Infrared portion:** It covers the wavelength range from approximately 0.7 µm to 100 µm. The infrared region can be divided into two categories based on their radiation properties - the reflected IR and the emitted or thermal IR. The reflected IR covers wavelengths from 0.7 µm to 3.0 µm. The thermal IR region is essentially the radiation that is emitted from the Earth's surface in the form of heat. The thermal IR covers wavelengths from 3.0 µm to 100 µm.
4. **Microwave portion:** It covers the longest wavelengths used for remote sensing ranging from about 1 mm to 1 m. The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts.

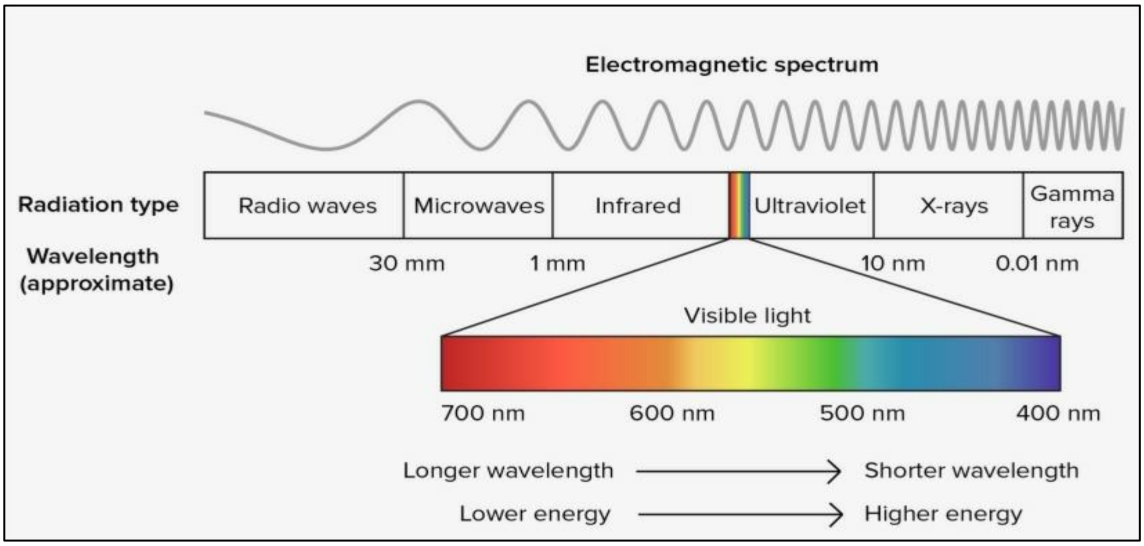

Fig 2: Electromagnetic Spectrum

Radiation - Atmosphere Interactions

Before reaching the Earth's surface, radiation used for remote sensing travels through some distance of the Earth's atmosphere. The incoming light and radiation can be affected by particles and gases present in the atmosphere. These effects occur by the mechanisms of scattering and absorption.

Absorption is one of the major mechanism at work when electromagnetic radiation interacts with the atmosphere. This phenomenon occurs when the molecules in the atmosphere absorb energy at various wavelengths. Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation.

Scattering occurs when particles or large gas molecules present in the atmosphere interacts with the electromagnetic radiation and causes it's redirection from original path. The amount of scattering depends on various factors such as the wavelength of the radiation, the abundance of particles or gases, and the distance the radiation travels through the atmosphere.

There are three types of scattering which take place

1. **Rayleigh scattering:** It occurs when atmospheric particles are very small in size as compared to the wavelength of the radiation. These particles include small specks of dust or nitrogen and oxygen molecules. It causes shorter wavelengths of energy to be scattered much as compared to longer wavelengths.
2. **Mie scattering:** It occurs when the particles are about the same size as the wavelength of the radiation. These particles include dust, pollen, smoke and water vapour which tends to affect longer wavelengths than those affected by Rayleigh scattering. This type of scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast.
3. **Nonselective scattering:** This occurs when the particles are much larger than the wavelength of the radiation. Water droplets and large dust particles can cause this type of scattering. All wavelengths are scattered about equally.

Radiation - Target Interactions

Radiation that is not absorbed or scattered in the atmosphere reaches and interacts with the Earth's surface. There are three forms of interactions that takes place when energy strikes, or is incident (I) upon the surface. These are: absorption (A); transmission (T); and reflection (R). The proportions of interaction depends on the wavelength of the energy and the material and condition of the feature (fig. 3)

Absorption (A) occurs when radiation is absorbed into the target while transmission (T) occurs when radiation passes through a target. Reflection (R) occurs when radiation "bounces" off the target and is redirected.

Fig 3: Radiation – Target interaction

Resolution

Resolution refers to the number of pixels in an image. It is sometimes identified by the width and height of the image as well as the total number of pixels in the image.

1. **Spatial resolution:** It refers to the size of the smallest possible feature that can be detected. Every remote sensing system has a limit on how small an object on the earth's surface can be and still be "seen" by a sensor as being separate from its surroundings.
2. **Spectral resolution:** It describes the ability of a sensor to define fine wavelength intervals. The finer the spectral resolution, the narrower is the wavelength range for a particular band.
3. **Radiometric resolution:** The radiometric resolution of an imaging system describes its ability to discriminate very minute differences in energy. The finer the radiometric resolution of a sensor, the more sensitive it is to detecting small differences in reflected or emitted energy.

4. **Temporal resolution:** It is the ability to collect imagery of the same area of the Earth's surface at different periods of time.

Remote Sensing Platforms

In order to collect and record energy reflected or emitted from a target, the sensor must reside on a stable platform removed from the target. Platforms for remote sensors may be situated on the ground, on an aircraft or balloon, or on a spacecraft or satellite outside of the Earth's atmosphere (fig. 4)

Ground-based sensors are used to record detailed information about the surface as compared to airborne or space based sensors. In some cases, this can be used for better characterization of the target which is being imaged by the other sensors, making it possible to better understand the information in the imagery. The sensors may be placed on a ladder, tall building, crane, etc.

Aerial platforms are primarily stable wing aircraft, although helicopters are occasionally used. Aircraft are used to collect very detailed images and facilitate the collection of data over virtually any portion of the Earth's surface at any time.

In space, remote sensing is sometimes conducted from the space shuttle or, more commonly, from satellites.

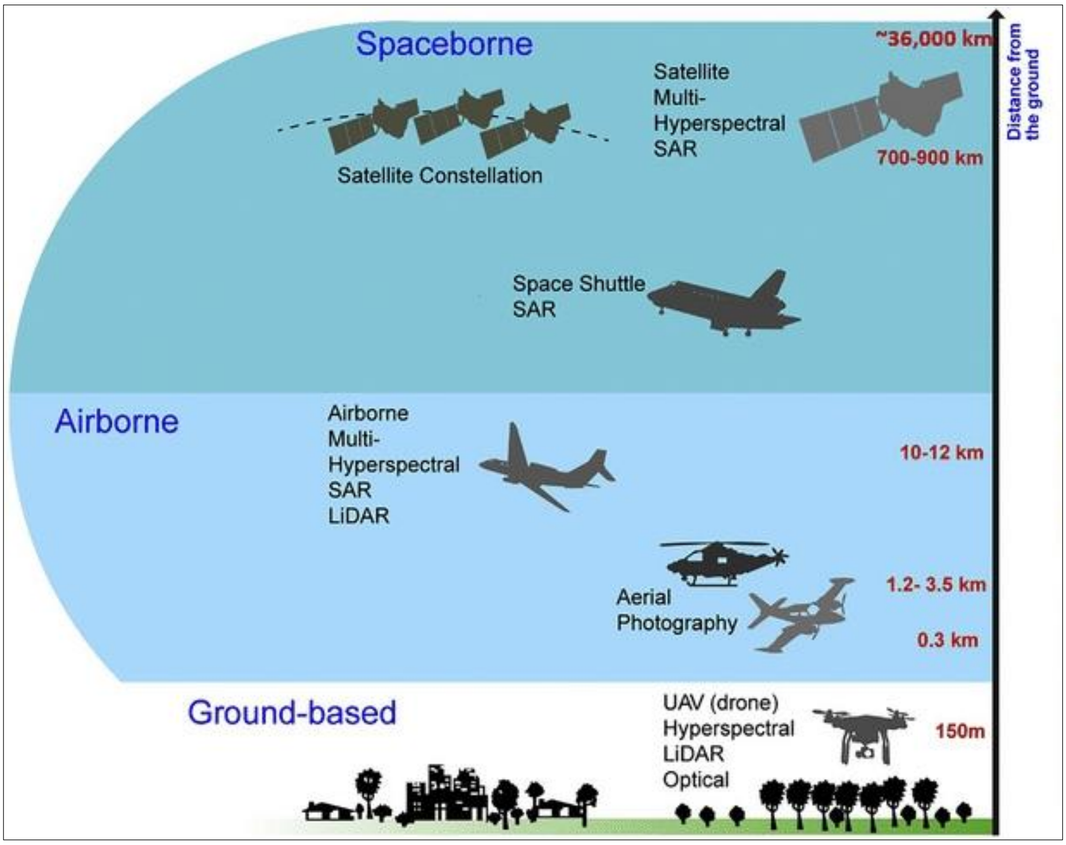

Fig 4: Remote Sensing Platforms

Types of Remote Sensing

1. Based on the source of energy, remote sensing is of two types – passive remote sensing and active remote sensing.

a. Passive sensors can only be used to detect energy when the naturally occurring energy is available. For all reflected energy, this can only take place during the time when the sun is illuminating the Earth.

b. Active sensors provide their own energy source for illumination. The sensor emits radiation which is directed towards the target under observation. The radiation reflected from that target is detected and measured by the sensor.

2. Based on Range of Electromagnetic Spectrum: These are of 3 types.

a. **Visible Remote Sensing:** It measures the wavelength from 300 nm to 3000 nm. It includes visible, near infrared, middle infrared and short wave infrared portion.

b. **Thermal Remote Sensing:** It measures the wavelength from 3000 to 14000 nm. It records the energy emitted from the earth.

c. **Microwave Remote Sensing:** It measures the wavelength of 1 mm to 1 m. Active sensors are used in this type of remote sensing, hence this can operate in all weather and environmental conditions.

GIS

Geographic Information Systems are computer-based systems that deals with virtually any type of information about features that can be referenced by geographical location. These systems are capable of handling both locational data and attribute data about the features.

Components of GIS

GIS comprises of the following six components

1. **Hardware:** It refers to powerful computers, printers, output devices, such as monitors, input devices, and large amounts of disk space to store the large GIS data sets.
2. **Software:** It refers to the free and commercial software packages which allows GIS users to perform GIS functions such as the manipulation, storage, query and analysis of spatial and non-spatial information.

3. **Data:** It refers to all spatial and non-spatial information stored in a digital format on the computer. A GIS can visualize the data as a map, graph or other graphic, which helps the user to understand and choose through massive amounts of data.
4. **Methods:** It includes the formulas, statistics, analysis and algorithms that are used to turn data into information, which aids easy interpretation of the information.
5. **People:** It refers to the users of GIS. This includes both the general public as well as the skilled GIS professionals.
6. **Network:** It refers to both the computer and social network.

Applications In fruit crops

1. **Mapping of orchards and estimation of cultivable land area:** A study was carried out by Sharma and Panigrahi (2010) [5] to generate block wise database on apple plantation in Shimla district of Himachal Pradesh. Apple orchards were mapped using high resolution remote sensing data from most advance Indian Remote Sensing (IRS) satellite P6. More than ninety percent accuracy has been achieved using remote sensing data. The salient results obtained are: Shimla is major apple growing block having 376.30Sq. Km. area under apple orchards. Elevation range 2000-3000m and Slope 21- 40° is supporting majority of orchards in Shimla district. The terrain parameters indicate that dense orchards lie in elevation range of 2000-3000m. Another research on apple orchard area estimation using remote sensing and agro-metrology land based observation was performed by Mustaq and Asima (2014) [4] in Pulwama district of Kashmir valley. Landsat and AWIFS digital data were utilized to monitor and estimate area under apple orchards. It was found that majority of apple orchards (89.82%) were concentrated between elevation range 1500-2000 mts, elevation above (2000m) occupied 10% area while 0% under lower elevations <1500m). The terrain parameters indicated that the dense orchards lie in the elevation range 1500-2000 meters. A recent study was carried out by Verma *et al.* (2020) [8] to classify the mango orchards of Lucknow district using multi-temporal Landsat 8 operational land imager (OLI) and images from year 2015 to 2017 were observed and further mango orchard area was also estimated. It was reported that the acreage of mango increased consequently from 2015 (2807 ha), 2016 (2947 ha) to 2966 ha in 2017.
2. **Land assessment and suitability:** Yegade *et al.* (2013) [9] carried out a study in the south-west part of Maharashtra, in the Sangola Tahsil of Solapur district to evaluate the suitability of the land for pomegranate production by using Multicriteria logic and GIS application. The factors that were considered for evaluation of the land suitability for crop production were slope, soil drainage, soil texture, soil depth, soil type, ground water availability and the present land-use of the study area. The crop-land evaluation results of the study identified that in the study area, 4986 ha of the total Pomegranate crop area was being used, which were under highly suitable areas and 3255 ha were under moderately suitable areas. A substantial portion (5596 ha) was under marginally suitable areas. This research provided information at local level that could be used by farmers to select cropping patterns and suitability.
3. **Crop inventory of orchard crops:** Chaudhari *et al.* (2019) [1] carried out a study for developing research methodology for area assessment of three major fruit crops such as Banana, Mango and Citrus over 20 districts in four states *viz*. Gujarat, Madhya Pradesh, Uttar Pradesh and Bihar. Appropriate bio-window for analysing different crop types was selected and mapping of crops was done using pixel based hybrid classification i.e. un-supervised ISODATA clustering plus supervised MXL classification as well as object based classification of high resolution remote sensing data (Resourcesat LISS III and/or LISS IV, Cartosat – 1 PAN) followed by their accuracy assessment and their comparison with departmental reported statistics. Overall, the classification accuracy was more than 80% for all the crops. The study, showed the usefulness of satellite remote sensing data for crop area estimation of major horticultural crops.
4. **Precise application of fertilizer:** Zaman *et al*. (2005) [10] have studied variable rate nitrogen application in Florida citrus based on ultrasonically-sensed tree size. Tree canopy sizes were measured real-time in a typical 17-ha Valencia grove with an automated ultrasonic sensor system equipped with Differential Global Positioning System (DGPS). Prescription maps for variable application of nitrogen fertilizer were generated from ultrasonically scanned tree sizes on a single tree basis using ArcView GIS and Midtech Fieldware. Leaf samples from trees with different canopy sizes, which had been fertilized at a conventional uniform rate of 270 kg N/ha/y, were analyzed for nitrogen concentration. Analysis of 2980 tree spaces in the grove showed a skewed size distribution, with 62% in the 0- to 100-m^3/tree volume classes and a median volume of 79 m^3 /tree. The tree volumes ranged from 0 to 240 m^3/tree. Regression analysis showed that trees with excess leaf nitrogen (>3%) had canopies less than 100 m^3. These trees receiving excess nitrogen are likely to have lower fruit yields and quality, and wasted fertilizer nitrates may leach beyond the root zone to groundwater. In order to rectify the excess fertilization of smaller trees, a granular fertilizer spreader with hydraulically powered split−chain outputs controlled with a MidTech Legacy 6000 controller was used for variable rate application of nitrogen in one−half of the grove. A 38% to 40% saving in granular fertilizer cost was achieved for this grove when variable N rates were implemented on a per-tree basis ranging from 135 to 270 kg N/ha/y.
5. **Detection of abiotic stress:** Abiotic stress such as deficiency of moisture can also be identified through remote sensing technology. Several techniques such as high spatial resolution multispectral and thermal airborne imagery were employed to monitor crown temperature and the Photochemical Reflectance Index (PRI) in peach orchards. Different irrigation regimes included sustained and regulated deficit irrigation strategies, were utilised to induce stress. The results depict that a difference in reflectance pattern between well irrigated and stressed plants can be observed (Saurez *et al.*, 2010) [7].
6. **Quality assessment:** Quality is one of the major parameter which is of concern to the producer. Johnson *et al* (2001) [3] assessed the quality of grape wine which is directly correlated to the vigour of vine. Remotely sensed

vegetation index imagery was used to establish sub–block management zones in a 3ha commercial vineyard of Chardonnay wine grapes. Subsequent ground based measurements revealed a clear differentiation between low and high vigour zones with respect to biomass (primarily shoot vigour), vine water status, and most importantly, fruit and wine character. Harvesting by vigour zones allowed for the extraction of unique wine lots from a block that was historically treated as a single management unit. This aspect alone has value in that the winemaker was provided with greater flexibility in the final blending process.

7. **Detection of pest occurrence:** Remote sensing techniques can reduce pest monitoring costs in orchards. Ludeling *et al*. (2009) [2] evaluated the feasibility of detecting spider mite damage in orchards by measuring visible and near infrared reflectance of 1153 leaves and 392 canopies in 11 peach orchards in California. Pairs of significant wavelengths, identified by Partial Least Squares regression, were combined into normalized difference indices. These indices were evaluated for correlation with mite damage. Eight spectral regions for leaves and two regions for canopies (at blue and red wavelengths) were significantly correlated with mite damage. Index values were linearly correlated with mite damage (R^2=0.47), allowing identification of mite hotspots in orchards. However, better standardization of aerial imagery and accounting for perturbing environmental factors will be necessary for making this technique applicable for early mite detection.
8. **Detection of disease incidence:** Physiological stress in trees causes changes in photosynthetic pigments such as chlorophyll, carotenoids and other factors which can easily be detected through changes in spectral reflectance. With improvements in spatial, spectral and temporal resolution of remote sensing, multispectral imagery remains advantageous due to its real-time or near real-time imagery for visual assessment. With this imagery technique it is possible to detect infected trees and healthy trees. Sindhuja *et al.*, (2013) [6] reported that there was a difference in average reflectance. Values of the healthy trees in the visible region were lower than those in the near infrared region, while the opposite was the case for HLB-infected trees. This could help in taking up of immediate control measures, so that spread of disease could be minimised.

Conclusion
Remote sensing and GIS are rapidly proving their potential for applications in crop biomass detection, soil properties, soil moisture and nutrient content, green fruit counts, crop yield estimation, damage by biotic and abiotic stresses etc. These technologies are authentic resources of information for identifying, classifying, mapping, monitoring and planning of natural resources and disaster mitigation and management. They have a promising future for site specific management, precision horticulture, market planning and export. Remote Sensing and GIS has proved to be an influential tool for the environmental monitoring in several instances.

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