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Remote Sensing Applications in Fruit Crops: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Horticulture has become a significant agricultural venture in accelerating economic growth. Its contribution to a nation's food security, nutritional well-being, and poverty reduction and employment opportunities is pivotal. Among its various facets, fruit crops hold a prominent position, comprising a significance share of horticultural production. However, the cultivation of fruit crops demands considerable capital investment and labor input. Embracing modern technologies for fruit orchard advancement and maximizing production potential is thus deemed essential. In today's age, remote sensing emerges as a modern solution, providing efficient technology for managing crops in specific locations. Remote sensing, or RS, serves as a potent instrument facilitating the gathering and refreshing of data to formulate precise management strategies. Through the acquisition of electromagnetic data and imagery, RS enables straightforward manipulation via computer systems. Remote sensing has the potential to mitigate risks and limit harm, proving especially valuable for tailored management and precise agricultural practices, such as identifying crops, estimating areas, managing soil and nutrients, gauging biomass and yields, and evaluating damage caused by both living organisms and environmental factors. RS offers multifaceted benefits, including risk reduction, damage minimization and increased land productivity, thereby contributing to employment generation, enhanced exports and improved economic conditions, while also ensuring food and nutritional security.

Keywords: Aerial imagery; monitoring; precision; remote sensing; satellites; site specific.

1. INTRODUCTION

Fruit crops play a vital role in ensuring the nation's food security and nutritional well-being, necessitating an increase in both their quantity and quality (Ganeshamurthy et al., 2011). The term "remote sensing" refers to the method of acquiring information about land, water, or objects without any physical contact between the sensor and the subject under investigation. Here, "remote" indicates the absence of direct contact with the object, while "sensing" denotes the acquisition of information (Jensen, 2009). This process involves measuring or collecting data regarding an object or phenomenon using a recording device that is not situated close to the object or phenomenon being studied (Misra, 2022). It is an interdisciplinary method encompassing several fields like electronics, computers, spectroscopy, optics, and satellite launch. The fundamentals of each of these sciences are crucial, and remote sensing applications make use of them (Gupta 2017). The first TIROS meteorological satellite was launched in 1960, and a few years later, Landsat was launched. In 1961, the project within the United States Navy focused on analyzing aerial images was rebranded as "remote sensing." The term was formally introduced during a United Nations conference on the peaceful use of space in 1968, where its potential applications in agriculture and forestry were explored in several papers. The United States launched its first satellite dedicated to remote sensing technology in July 1972. Remote sensing efforts in Canada commenced in 1969. Since the 2000s, there has been continuous research on high-resolution data and the development of hyperspectral sensors (Cohen, 2000). The utilization of Unmanned Aerial Vehicles (UAVs) equipped with sensor systems to analyze the spatial patterns of photosynthetic activity in banana plantations can aid in identifying and mapping variations in fruit quality and yield. This approach holds promise for investigating the spatial distribution of factors influencing production, ultimately enhancing agricultural efficiency (Machovina et al., 2016). Unmanned Aerial Vehicle (UAV)-based remote sensing (RS) is extensively employed in various scientific domains such as geography, land surveying, and various earth science disciplines. Recently, this technology has also been applied in fruit science, as highlighted by Green in 2020.

Remote sensing is the process by which information on the Earth's surface is obtained without physically touching the surface, usually by means of satellites, drones, and aerial photographs. In fruit crop farming, remote sensing has turned out to be an effective tool in the field of precision agriculture. It allows farmers, researchers, and agricultural managers to track crop health, soil status, water stress, pest and disease infestation, and general field variability with precision and frequency.

Decision-makers are able to make site-specific interventions through analyzing remotely sensed data, thus maximizing inputs like fertilizers, irrigation, and pesticides. This not only supports productivity and fruit quality improvement, but also enhances substantially the efficiency of resource use and encourages sustainable agriculture. In addition, remote sensing aids yield prediction, early warning, and long-term planning through its provision of real-time and historical trends in data. Consequently, remote sensing is important in ensuring that fruit production systems are resilient and climate-smart.

India ranks as the second-largest fruit producer globally after China, with 7.06 million hectares of area, 104.16 million metric tons of production, and a productivity of 14.7 t/ha (FAO, 2020). Regular monitoring of orchards is crucial for enhancing fruit output, yet it poses challenges due to the vast area coverage. Remote sensing emerges as one of the latest and most advanced technologies for gathering precise data on various parameters required by the horticultural industry, especially for fruit crops across extensive areas (Pujar et al., 2017). The integration of Geographic Information System (GIS) with aerial or satellite imagery linked to Global Positioning System (GPS) data facilitates the effective implementation of site-specific crop management (SSCM) for fruit and nut crops. Adopting SSCM for fruit and nuts aids in optimizing resource utilization and increasing productivity. When orchards are delineated using spatial technology, additional information is generated, aiding in management decision-making processes. This information encompasses determining the timing and quantity of irrigation, optimizing pesticide use for pest and disease control, managing fertilizer application, and estimating fruit yield (Deb et al., 2018).

The proposed approach involves the detection and classification of citrus diseases in citrus fruits using a digital camera, segmentation techniques, and Principal Component Analysis (PCA) for feature selection. The methodology is evaluated using various datasets to identify and categorize citrus diseases such as melanoses, anthracnose, black spot, canker, scab, and greening (Sharif et al., 2018). With recent advancements in optical sensing technology, hyperspectral imaging emerges as one of the most effective methods for non-contact fruit quality detection, including maturity detection for various fruits such as persimmons, olives, nectarines, strawberries, and bananitos (Pu et al., 2019; Munera et al., 2017a, 2017b; Cabrera et al., 2018; Zhang et al., 2016). However, challenges remain in successfully implementing hyperspectral photography in the field, including limitations in light sources, wind interference, and crop overlap. Additionally, exploring the combination of hyperspectral imaging with deep learning holds promise for extracting specific information and comprehending vast datasets.

Remote sensing, when employed as a precision farming tool, holds potential for addressing challenges associated with fruit cultivation. However, its successful implementation depends on several technical factors. Nevertheless, the efficient adoption of remote sensing in agricultural sectors faces obstacles in developing countries like India due to a lack of requisite technical expertise. Developed countries have already integrated these technologies into their fruit farming practices. This presents an opportunity for less affluent nations to harness the benefits of remote sensing by providing financial assistance and proactive technical guidance to farmers. The implementation of such support mechanisms holds promise for increasing fruit crop production (Lamba et al., 2021).

The purpose of this review paper is to provide a comprehensive overview of many aspects of remote sensing, including its principles and applications, in a manner that is both instructive and easy to understand.

Sensors for monitoring fruit crops: Electromagnetic radiation is detected by sensors, which then transform it into a signal that can be stored or shown as an image or set of numbers (Iqbal et al 2023). Sensors such as microwave radiometers, spectrometers, and cameras are among the various sorts of sensors that are utilized in the cultivation of fruit crops. Thermal remote sensing is a technique that involves the collection of thermal pictures through the utilization of thermal sensors that are either portable or hand-held and are associated with optical systems that are mounted on an aeroplane or satellite (Peng et al 2023). This technology is non-invasive, non-contact, and

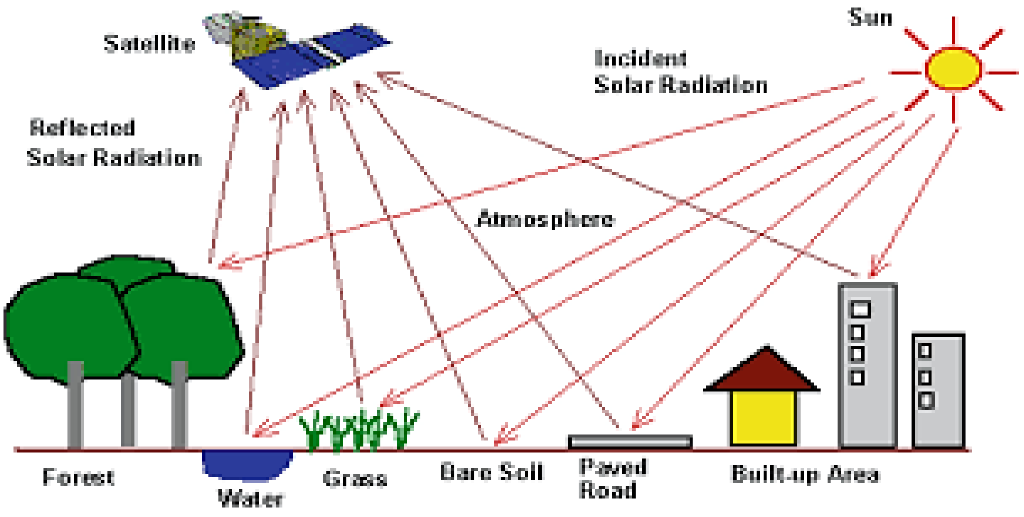

Fig. 1. Use of remote sensing in fruit crop
(Source, Prabhakar et al., 2022)

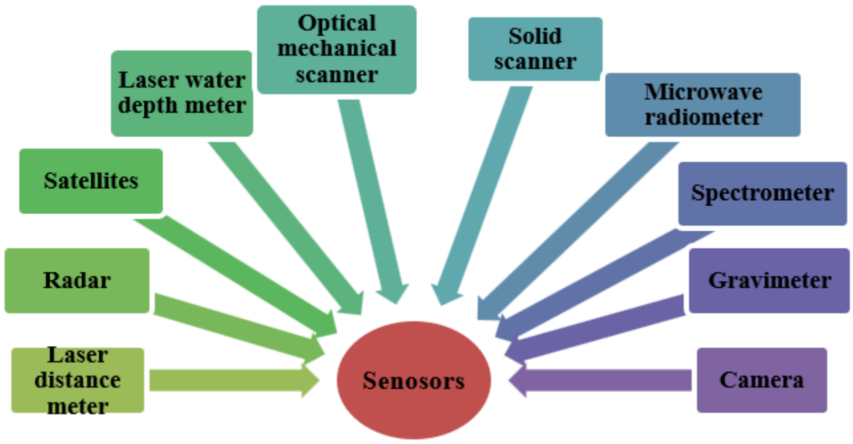

Fig. 2. Types of sensors used in monitoring for fruit crops

non-destructive, which makes it effective in a variety of fields which involve the generation or loss of heat over a period of time (Sutherland et al 2023). Remote sensing uses various sensors for fruit crop monitoring including (Zheng et al 2021):

1. **Microwave radiometer:** Used to measure the temperature of crops by sensing microwave emissions.
2. **Gravimeter:** Used to measure the gravitational pull of crops to determine their moisture content.
3. **Spectrometer:** Used to measure the reflection or absorption of light by crops to determine their health and growth.
4. **Camera:** Utilized to acquire detailed images of crops for analysis and surveillance purposes.
5. **Solid scanner:** Used to scan the surface of crops to detect abnormalities or damage.
6. **Optical mechanical scanner:** Used to capture images of crops in various spectral bands for detailed analysis.
7. **Laser water depth meter:** Used to measure the water content of soil and crops.
8. **Laser distance meter:** Used to measure the height and density of crops.
9. **Radar:** Used to detect changes in crop growth and moisture content.
10. **Satellites:** Used to monitor crops from space and provide data on crop health, yield, and growth.

Application of remote sensing in fruit crops: Remote sensing has several applications in fruit crop monitoring, some of which are:

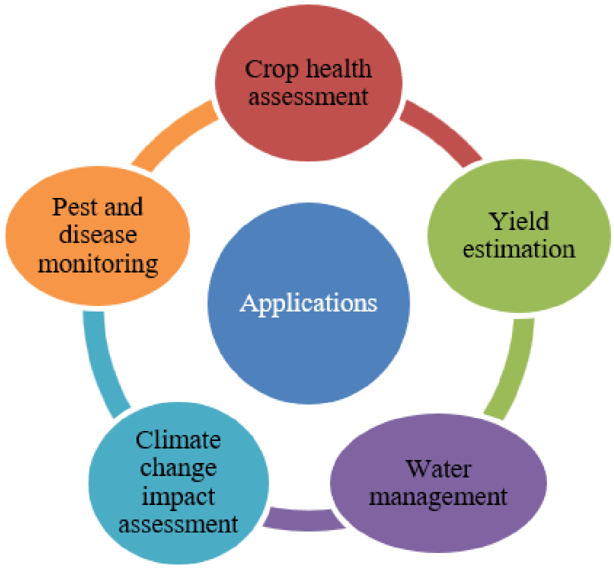

Fig. 3. Applications of remote sensing in fruit crops

1. ***Crop health assessment:*** Through the examination of the spectral signatures of fruit crops, remote sensing data can be utilized to ascertain the state of health and vitality of these crops. It is possible to utilize this information to determine which parts of the orchard require attention, including those that are afflicted with diseases, pests, or inadequacies in nourishment (Pande abd Moharir 2023).
2. ***Yield estimation:*** Remote sensing can help estimate fruit yield by analyzing crop vigor and flowering patterns. This information can be used to optimize harvesting and fruit storage (Psiroukis et al 2023). Sarron et al (2018) carried an experimental trial on mango yield mapping by using Unmanned aerial vehicle at Niayes region of France.
3. ***Water management:*** Fruit crop irrigation schedules, soil moisture content, and water usage efficiency can all be tracked by remote sensing. By using this information, water management techniques can be improved and water consumption can be decreased (Koech and Langat, 2018). Hyper spectral remote sensing was used by Mahajan et al (2021) to track the foliar nutritional status of mangos in India.
4. ***Pest and disease monitoring:*** Remote sensing offers a valuable tool for detecting and monitoring pest and disease outbreaks in fruit crops. This technology provides crucial information that can be leveraged to develop early warning systems, leading to more effective pest and disease management strategies and potentially reducing the reliance on pesticides (Liao et al., 2012). In a study conducted by Chang et al. (2020) at Texas A&M University in the USA, research focused on the application of Unmanned Aerial Vehicle (UAV) multispectral imagery for the detection of citrus greening. This research underscores the potential of advanced imaging techniques in enhancing the early detection and management of citrus diseases, thereby contributing to more sustainable agricultural practices.

Climate change impact assessment: Remote sensing technology offers a means to evaluate shifts in environmental conditions essential for plant growth, such as temperature fluctuations, alterations in precipitation patterns, and changes in solar radiation. Through the application of remote sensing techniques, both researchers and farmers can effectively assess how climate change influences the cultivation and well-being of fruit crops. This innovative approach facilitates a more thorough comprehension of the effects of climatic variations on fruit production, aiding in the formulation of adaptive strategies to mitigate potential risks and enhance crop yields. This information can be utilized to devise adaptation measures aimed at lessening the impact of climate change on fruit crops (Cleland et al., 2007).

1.1 Estimation of Cultivable Land Area and Mapping of Orchards

An area can be regularly, synoptically, multispectrally, and multitemporally covered by remote sensing equipment. In the Pulwama area of the Kashmir valley, Ganie and Nusrath (2014) assessed the size of the apple orchard using remote sensing and land-based agro-metrology observations. In order to better characterize apple orchards, they have included other topography features, such as elevation, slope, and aspect. These factors can also be used to expand the area of apple orchards. Apple orchard acreage was estimated and monitored using digital data from Landsat and AWIFS. The photos were geo-referenced using topographical maps of the Survey of India (SOl) at a scale of 1:50,000. Ancillary data was obtained in the form of crop statistics from the State department of horticulture. With this information, they discovered that the bulk of apple orchards (89.82%) are located in the 1500–2000 m elevation range. The apple area is approximately 10% above 2000 meters, and it is approximately 0% below 1500 meters. The dense orchards are located between 1500 and 2000 meters above sea level, according to the terrain conditions. As a result, these locations can serve as benchmarks for standardizing site appropriateness and apple orchard management plans. Given that the density and plantation age matched well, densely populated locations might require planning for revitalization.

1.2 Site-Specific Grove Management and Variable Fertilizer

Enhancing the profitability of horticulture while promoting environmental protection can be achieved through site-specific grove management. This approach involves adjusting the delivery of inputs such as fertilizers based on the size of the trees. Zaman et al. (2005) conducted a study on variable rate nitrogen application in Florida citrus groves using ultrasonically detected tree sizes. In a typical 17-hectare Valencia orange grove, tree canopy diameters were continuously monitored using an automated ultrasonic sensor system equipped with a Differential Global Positioning System (DGPS). Utilizing ArcView GIS and Midtech Fieldware software, prescription maps were generated for the variable application of nitrogen fertilizer based on the ultrasonically measured tree diameters on an individual tree basis.

1.3 Detection of Water Stress

Remote sensing technology can assist in identifying water stress in leaves by observing alterations in color. Researchers employed several methods, including thermal and multispectral aerial photography with high spatial resolution, to observe the Photochemical Reflectance Index (PRI) and crown temperature in peach orchards. Various irrigation strategies, such as controlled deficit irrigation and continuous irrigation, were applied to induce stress conditions. The study conducted by Saurez et al. (2010) demonstrated clear differences in reflectance patterns between stressed plants and those adequately irrigated.

1.4 Assessment of Quality

Quality is a paramount concern and ultimate objective for every producer, especially in the context of grapevine viability, which directly impacts the quality of wine produced (Johnson et al., 2001). In a 3-hectare commercial vineyard growing Chardonnay wine grapes, sub-block management zones were established using remotely sensed vegetation index imaging. Subsequent ground-based assessments revealed noticeable differences between zones with low and high vine vigor in terms of biomass (primarily shoot vigor), vine moisture content, and, significantly, fruit and wine characteristics. By harvesting according to vigor zones, it became feasible to segregate distinct wine lots from a block previously managed as a single unit. This capability is particularly valuable as it affords winemakers greater flexibility in refining the final blending process.

1.5 Early Detection of Pest Infestation

Utilizing remote sensing techniques can lower the expenses associated with pest monitoring in orchards. In a study by Ludeling et al. (2009), the visible and near-infrared reflectance of 1153 leaves and 392 canopies from 11 peach orchards in California were analyzed. The objective was to assess the efficacy of identifying spider mite damage in orchards using this approach. The researchers developed normalized difference indices by combining key wavelengths identified through partial least squares regression and examined the correlation between these indices and mite damage. The findings indicated a significant correlation between mite damage and eight spectral regions for leaves and two regions for canopies,

Table 1. Achievement in fruit crops through remote sensing with different tools

S. No	Remote sensing tools	Attributes	Name of fruit crops	References
1	Scanning	Estimation of Sugar, sweetness index, chlorophyll	Peach	Slaughter, (1995)
2	Scanning	Estimation of Sugar, sweetness index, chlorophyll	Peach cv. Nectarine	Slaughter (1995)
3	CCD with band pass filters	Bruises	Peach cv.Vesubio	Zwiggelaar et al., (1996)
4	Scanning	Citric acid	Mandarin cv. Satsuma	Miyamoto et al 1998
5	PDA	Dry matter	Kiwifruit cv. Hayward	Osborne and Kunnemeyer, (1999)
6	NIR camera with vidicon tube, mono chromator controlled light source	Defects	Cherry	Guyer and Yang, (2000)
7	Scanning	Acidity, firmness and storage period	Mango cv. Tommy Atkins	Schmilovitch et al., (2000)
8	CCD camera, combination with MIR camera	Stem and calyx identifications	Apple cv. Red Delicious	Wen and Tao, (2000)
9	Distribution of time of flight	Anthocyanin's, carotenoids, chlorophylls and effective path length	Apples, peaches, kiwifruits and tomatoes	Cubeddu et al., (2001)
10	FT NIR, Scanning	Freshness, acidity	Various apple cultivars	Peirs et al., (2002a)
11	PDA	Dry matter content	Avocado cv. Mill	Clark et al., (2003a,b)
12	PDA	Brown heart disorder	Apple cv. Braeburn	Clark et al., 2003a,b
13	Hyper and multispectral spectroscopy in the visible range	Anthocyanin's, carotenoids and chlorophylls	Apple	Merzlyak et al 2003
14	In GaAs camera with imaging spectrograph	Starch index	Apple cv. Jonagold and Boskoop	Peirs et al., (2003b)
15	CCD with filter wheel	Firmness	Apple cv. Red Delicious	Lu, (2004a)
16	CCD with filter wheel	Firmness and soluble solids content	Apple cv. Red Delicious	Lu, (2004b
17	Scanning	Dry matter content and starch	Mango cv. Caraboa	Saranwong et al., (2004)
18	FT NIR	Available acid	Peach cv. Honey sweet	Ying et al., (2005)
19	PDA	Fresh weight	Plum cv. Summerbrite	Golic and Walsh, (2006)
20	In GaAs camera with imaging spectrograph	Bitter pit	Apple cv. Red Delicious	Nicolai et al., (2006a)
21	CCD with imaging spectrograph	Firmness	Peach cv.Red Haven, Coral Star	Lu and Peng, (2006)
22	Near infrared spectroscopy	Fruit firmness, soluble solids content	Conference pear	Nicolai et al., (2007b)
23	GPS and GIS	Precision spraying of aldicarb to control citrus nematode	Citrus	Saline et al., (2007)
24	A sensor, a pump, and the solenoid	Spot spraying of citrus tree canopies for controlling	Citrus	Maja et al., (2009)

S. No	Remote sensing tools	Attributes	Name of fruit crops	References
	controlled spray	citrus psyllids		
25	Volumetric flow sensor	Measures the volume or the actual mass or weight of the fruit.	Citrus	Maja and Ehsani, (2010)
26	Fluorescence	Chlorophyll and Phenols	Apples	Lichtenthaler et al., (2012)
27	Photogrammetry	Size, shape, color, biospeckle	Food quality	Vijayarekha, (2012)
28	Machine vision based	Recognition of papaya disease viz; Black spot, powdery mildew on fruit, powdery mildew on leaf, brown spot, *Phytophthora* blight and Anthracnose	Papaya	Habib et al., (2018)
29	High resolution word view -3 imagery	Estimation of mango yield	Mango	Rahman et al., (2018)
30	Light detection and ranging (LiDAR) and multispectral imagery from UAV	Yield prediction	Apple	Chen et al., (2022)
31	Unmanned aerial vehicle (UAV) images with a ground sampling distance (GSD)	Detect the plant body	Pineapple	Shiu et al., (2023)

particularly at blue and red wavelengths. A linear relationship was observed between mite damage and index values (R^2 = 0.47), enabling the identification of mite hotspots in orchards. However, to render this technique suitable for early mite detection, enhancements in aerial imagery standardization and consideration of potential environmental disturbances are necessary.

1.6 Detection of Disease Incidence

Remote sensing plays an increasingly crucial role in precision agriculture by enabling the detection and characterization of crop health. Changes in spectral reflectance can indicate physiological stress in trees, attributed to alterations in photosynthetic pigments such as chlorophyll and carotenoids, among other factors. Despite advancements in spatial, spectral, and temporal resolutions, multispectral imaging remains the preferred method for visual assessments due to its provision of real-time or near-real-time imagery. This imaging technique facilitates the identification of both healthy and diseased trees. Research conducted by Sindhuja et al. (2013) revealed a significant difference in the average reflectance of healthy trees compared to those infected with HLB in the visible and near-infrared regions. Such findings could inform the prompt implementation of control measures to mitigate disease spread.

1.7 Challenges in Remote Sensing of Fruit Crops

Remote sensing presents valuable advantages for monitoring and managing fruit crops, yet it presents certain challenges that must be acknowledged and addressed to ensure accurate data interpretation and analysis.

1. **Canopy Structure:** The variability in fruit crop canopy structures, influenced by crop type and management practices, poses challenges in accurately interpreting remote sensing data (Chao et al., 2019).
2. **Phenological Stage:** Fruit crops undergo various growth stages, impacting canopy light reflectance. Precise identification of these stages is essential for accurate remote sensing analysis (Gong et al., 2021).
3. **Spectral Resolution:** The spectral resolution of remote sensing data affects the ability to differentiate between different crop and vegetation types (Govender et al., 2007).
4. **Spatial Resolution:** Spatial resolution impacts the accuracy of identifying and distinguishing between crops, especially in interplanted scenarios (Xue et al., 2023).
5. **Atmospheric Interference:** Atmospheric particles and gases can disrupt remote sensing data, reducing its accuracy (Rudke et al., 2023).
6. **Sensor Type:** Different sensors have varying capabilities and limitations, influencing the accuracy and utility of the collected data (Tamiminia et al., 2020).
7. **Data Processing:** Processing remote sensing data is intricate, and result accuracy depends on data quality and processing algorithms (Jianya et al., 2008).

Remote sensing's primary advantage lies in its capacity to rapidly and efficiently gather extensive data over large areas, without requiring personnel or equipment onsite. This saves time and resources and often provides a more comprehensive understanding of an area compared to conventional methods. Moreover, remote sensing allows for data collection at various times and locations, enabling detailed analysis. However, a key disadvantage is the potential for inaccuracies. Data collected from sensors not directly in contact with the study area can introduce errors. Furthermore, atmospheric conditions like clouds, haze, or smoke can compromise data reliability.

2. CONCLUSION

In order to enable site-specific management options that are economically advantageous, remote sensing is an invaluable technology that may be used to perform frequent monitoring of orchards at a high spatial resolution rate. Contributes to the reduction of monitoring expenses, improves the efficiency with which resources are used, reduces the overall cost of production, and increases profits. In the process of mitigating biotic and abiotic stress conditions, remote sensing can be of practical assistance. The primary barrier to the implementation of large-scale agricultural mechanization in India is the fragmentation of land. Considering the constraints, remote sensing is still a long way from being fully implemented in India. Adjustments that are based on needs and are appropriate will be worked out. It is necessary to make progress in the local technological skills.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that no generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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