

# Remote Sensing Applications in Plant Pathology - Use of Remote Sensing for Disease Detection and Monitoring

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Global agriculture faces increasing challenges from various stressors, including pests and diseases, which significantly affect crop yields. Although traditional pest management techniques have helped mitigate some of these issues, the uneven distribution of diseases over time and space can limit their effectiveness. Timely and precise disease assessment is crucial for effective management. Remote sensing technologies offer a rapid and objective way to monitor crop health by identifying differences in the spectral signatures of healthy and diseased plants. Recent advancements in imaging technologies such as multispectral, hyperspectral, infrared, and thermal sensors improve the accuracy of detecting and quantifying diseases at both field and regional levels. This continuous monitoring capability allows for early infection detection, supports informed decision-making, reduces unnecessary pesticide usage, and bolsters sustainable crop protection strategies.

**Keywords:** *Remote sensing, Plant pathogen, Detection, Monitoring, Imaging systems, Sensors*

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## Introduction

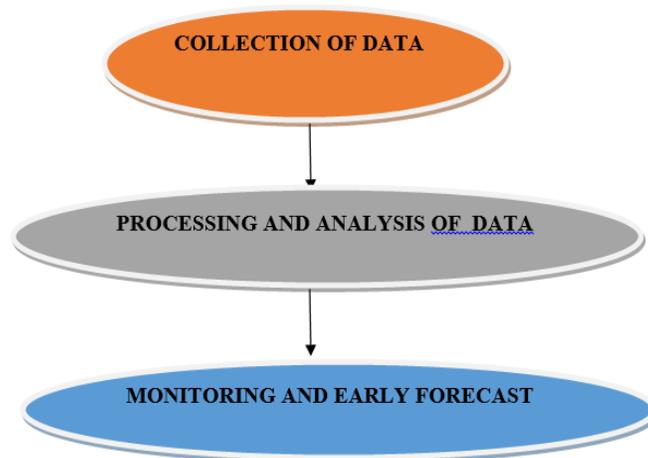
Global crop production faces significant challenges from pests and pathogens, including bacteria, fungi, and viruses. While human interventions can somewhat mitigate these threats, managing the losses caused by pests remains crucial, especially given that yield reductions from abiotic stresses can be even more profound. Studies estimate that plant pathogens are responsible for about 16% of yield losses worldwide (Oerke, 2006). It's clear that safeguarding plants from diseases and pest damage is vital for sustaining agricultural output. To achieve effective pest management, we need strategies that are efficient, sustainable, and reliable.

IPM combines mechanical, chemical, and biological control methods with supplementary technologies to enhance protection strategies (Oerke et al., 2010). Traditional disease management often operates under the assumption of uniform disease distribution across fields, which leads to the application of protective products at consistent rates. However, factors such as soil characteristics, topography, crop types, climate, and pathogen presence create a complex landscape of disease distribution that is anything but uniform. The distribution can be random or occur in patches and gradients.

Given the varying spatial and temporal dynamics of diseases across different sites, seasons, and even during the course of a single epidemic, accurate assessment at the field level is essential. Farmers often monitor disease incidence and severity by collecting leaf samples diagonally across a field to determine appropriate fungicide applications (Wolf and Verreet, 2002). Remote sensing is a quick and effective method for capturing and analyzing the spectral characteristics of the Earth’s surface from a variety of platforms such as satellites, aircraft, and ground systems. This cutting-edge technology serves as a valuable asset in boosting crop production and safeguarding crops. By examining the reflectance spectra of both healthy and diseased plants, remote sensing data analysis can help pinpoint infections (Cubero et al., 2024). Researchers delve into an array of sensor-specific parameters, including temporal, spatial, radiometric, and spectral resolutions, alongside imaging technologies like visible, infrared, thermal, multispectral, and hyperspectral sensing, to explore their potential for detecting plant diseases.

Many of these methods show great promise in the field of phytopathometry, allowing for accurate measurement of disease presence and severity. Some of the spectral methods such as Raman spectroscopy could be used to detect plant pathways induced by pathogens. These could be used to design and develop drones for early monitoring of pathogens (Murray et al., 2025). With the use of remote sensing technologies, diagnostic precision can be significantly enhanced, fostering sustainable and safe agricultural practices by reducing unnecessary pesticide applications. Continuous monitoring of crops via sensors enables early detection of infections or disease outbreak thresholds, leading to timely and focused management responses. Additionally, remote sensing supports a quantitative evaluation of disease severity, which aids in data-driven decision-making for crop protection. Recently an innovation of using unarmed aerial vehicle along with remote sensing is being investigated for enhanced crops health (Shukla et al., 2024)

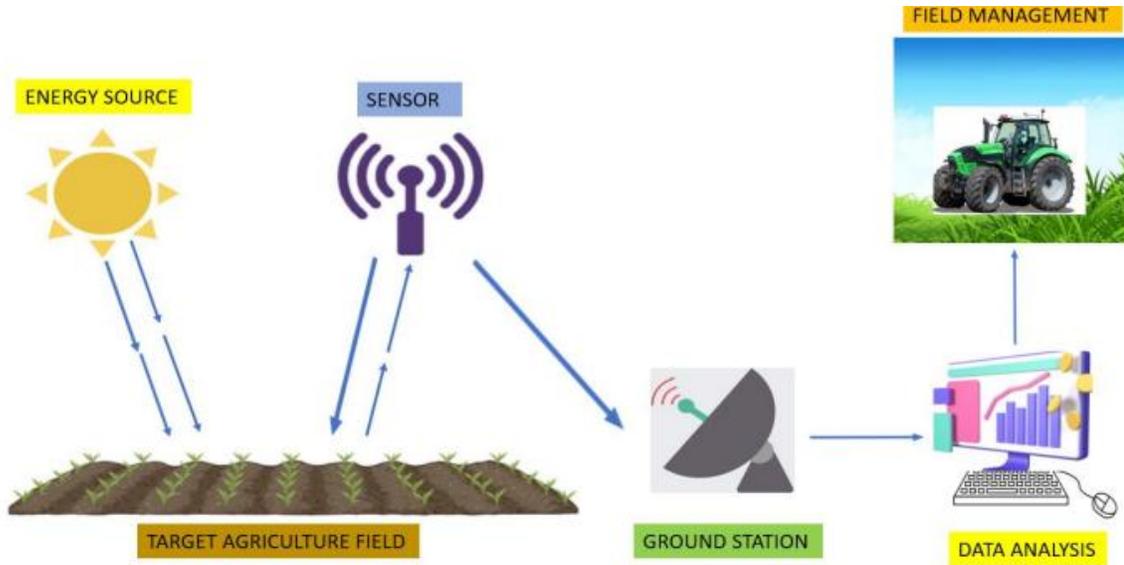
**Procedure for Detecting Plant Diseases**



Plant disease data can be obtained through constant monitoring either through spatial images or videos of a crop using satellites, unmanned aerial systems (UAVs), or ground sensors of multispectral, hyperspectral,

and thermal imaging. Analysis of data is done through differences in the red and near-infrared light reflectance indicates plant vigour, stress or chlorophyll content.

Algorithm based analysis is useful in detecting, differentiating and determining disease severity. Texture features of the image analysis helps in identifying the disease spread pattern. Deep machine learning and multi-temporal data is analysis is used to track the spread and outbreak of plant diseases. Disease mapping and forecasting helps in site specific management and application of fungicides for a better disease management.



**Figure 1. Process of remote sensing for Detection of plant Diseases**  
**Image Adapted from Parida et al., 2025**

**Role of Sensors**

Sensors can be categorized using various criteria. First, we have spectral sensors that operate across different parts of the electromagnetic spectrum, including visible (VIS), near-infrared (NIR), short-wave infrared (SWIR), thermal infrared (TIR), and radar domains. Next, based on their platform, sensors can be ground-based (proximal), mounted on unmanned aerial vehicles (UAVs), airborne, spaceborne, or even microscopic. Furthermore, when considering how they record data, sensors are divided into two types: Passive and Active. Passive sensors, like thermographic devices, detect naturally emitted radiation or reflected solar radiation, as seen in RGB or spectral cameras. In contrast, active sensors such as fluorescence systems, Synthetic Aperture Radar (SAR), and Light Detection and Ranging (LiDAR) emit their own radiation to interact with the target object. Additionally, sensors may be classified as either imaging or non-imaging, depending on the type of data they record (Oerke, 2018). The geometric relationships among the sensor, target, and radiation source become increasingly significant as the distance between them decreases. While active sensors remain unaffected by abiotic factors, their effectiveness is highly reliant on the geometry relating the emitter, detector, and object. It's also worth noting that the exposure time of electromagnetic radiation in active systems tends to be roughly twice that of passive systems. Beyond optical technologies, sensors designed to detect volatile organic compounds (VOCs) are gaining traction. These non-invasive, non-destructive, and passive sensors provide invaluable support for real-time plant health monitoring and disease detection.

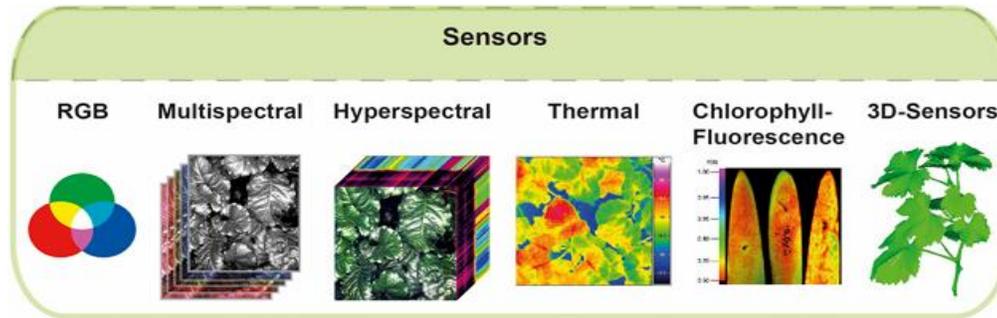


Figure 2. Images of optical sensing techniques. Image Adapted from Anne K.M (2016)

### Optical Sensors for Plant Disease Detection

Spectral information in the range of 350 to 2,500 nm is captured by radiation-sensitive detector systems that decompose electromagnetic radiation into its individual spectral components. Non-imaging spectrometers stand out for their high spectral resolution, allowing for the analysis of numerous narrow wavebands within this range. However, it's important to note that the spectral data acquired only reflects an averaged signal. Different imaging systems can record spectral data, each varying in spatial resolution: (a) a single wavelength or the cumulative sum of the 400–700 nm range (referred to as panchromatic); (b) essential color components such as red, green, and blue with a bandwidth of 60–80 nm (like standard RGB cameras and smartphones); (c) discrete and narrower bands, which include the near-infrared (NIR) region, characteristic of multispectral imaging; and (d) a wide array of spectral bands across a continuous spectrum in hyperspectral imaging, which excels in spectral resolution.

#### Examples of studies on plant diseases detection by different optical sensors (Mahlein, 2016) of the disease.

Sensor	Crop	Disease/Pathogen	Reference
RGB	Cotton	Bacterial angular ( <i>Xanthomonas campestris</i> )	Camargo and Smith (2009)
		Ascochyta blight ( <i>Ascochyta gossypii</i> )	
	Sugar beet	Cercospora leaf spot ( <i>Cercospora beticola</i> )	Neumann et al. (2014)
		Sugarbeet rust ( <i>Uromyces betae</i> )	
	Grapefruit	Citrus canker ( <i>X. axonopodis</i> )	Bock et al. (2008)
Tobacco	Anthracnose ( <i>Colletotrichum destructivum</i> )	Wijekoon et al. (2008)	
Spectral sensors	Barley	Net blotch ( <i>Pyrenophora teres</i> ), Brown rust ( <i>Puccinia hordei</i> ),	Kuska et al. (2015)
	Wheat	Head blight ( <i>Fusarium graminearum</i> )	Bravo et al. (2003), Moshou et al. (2004)
		Yellow rust ( <i>Puccinia striiformis f. sp. tritici</i> )	
	Sugarbeet	Cercospora leaf spot ( <i>C. beticola</i> ), Sugarbeet rust ( <i>U. betae</i> )	Mahlein et al. (2010, 2012) Bergstrasse et al. (2015)

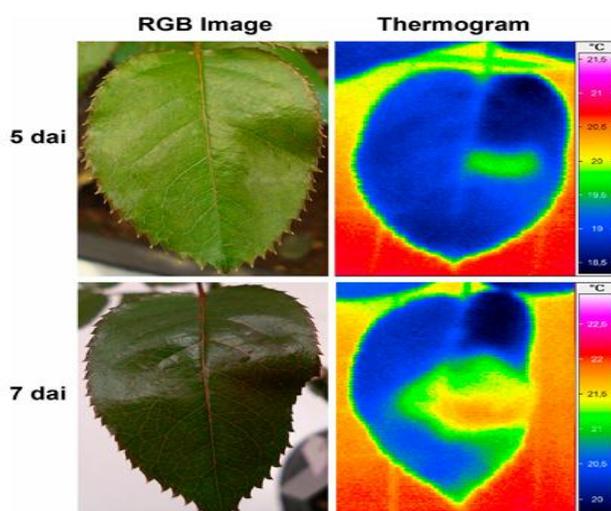
	Tomato	Late blight ( <i>Phytophthora infestans</i> )	Wang et al. (2008)
Thermal sensors	Sugarbeet	Cercospora leaf spot ( <i>C. beticola</i> )	Chaerle et al. (2004)
	Cucumber	Downy mildew ( <i>Pseudoperonospora cubensis</i> )	Oerke et al. (2006), Berdugo et al. (2014)
Fluorescence imaging	Wheat	Leaf rust ( <i>Puccinia triticina</i> ) Powdery mildew ( <i>Blumeria graminis f.sp. tritici</i> )	Burling et al. (2011)
	Sugarbeet	Cercospora leaf spot ( <i>C. beticola</i> )	Chaerle et al. (2007); Konanz et al. (2014)

### RGB –Imaging

Digital photography is an essential tool for identifying and assessing plant diseases. It’s user-friendly and produces RGB (red, green, and blue) images that aid in detecting, identifying, and quantifying disease symptoms. Additionally, digital image analysis serves as a valuable method for evaluating these symptoms. Software programs like ASSESS 2.0, Leaf Doctor, and Scion Image have been created to enhance the image-based quantification of disease incidence and severity.

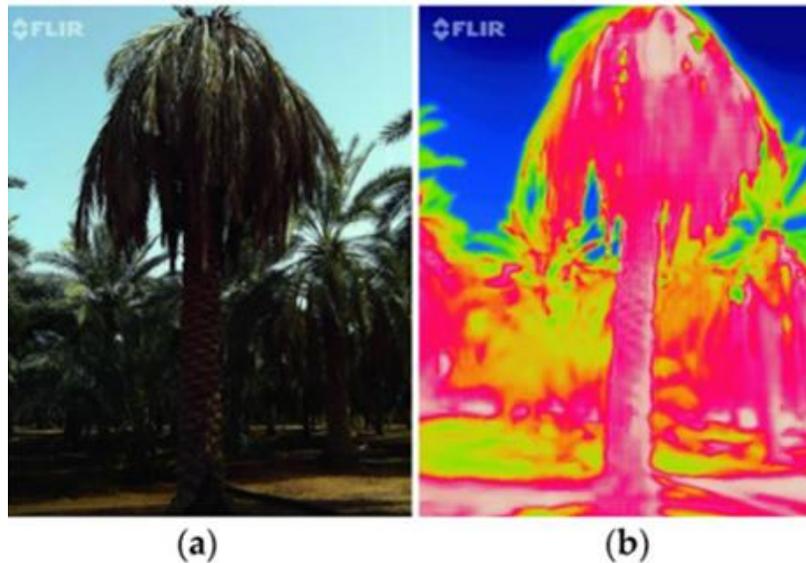
### Thermography

Infrared thermography (IRT) is frequently employed to measure the surface temperature of plants, crop canopies, or leaves, providing insights into water availability following stomatal or cuticular transpiration (Costa et al., 2013; Jones and Schofield, 2008). Thermal sensors can detect radiation in the thermal infrared region (8-14 μm) and represent it as false-color images to visualize temperature variations. This technique can be performed through ground-based, airborne, or spaceborne systems, allowing for quick imaging of temperature distributions across plant tissues and crop stands, which supports ongoing monitoring and measurement.



**Figure 3. Thermographic image of *Peronospora sparsa* colonization in the early stages after inoculation on 5 and 7 days in Rose leaf. Image Adapted from Anne K.M (2016)**

The use of thermal imaging for detecting plant diseases is primarily limited to root infections that affect water relations, impaired water transport in stems, altered stomatal conductance, and modified cuticular transpiration (Oerke and Steiner, 2010). For example, diseases such as powdery mildew can be challenging to identify under normal growing conditions through thermography. However, since infrared thermography is highly responsive to changes in transpiration, it can detect pathogen activity within plant tissues even before symptoms appear. Nevertheless, it's important to note that both biotic and abiotic stressors can produce similar temperature responses, which limits the diagnostic specificity of thermography.

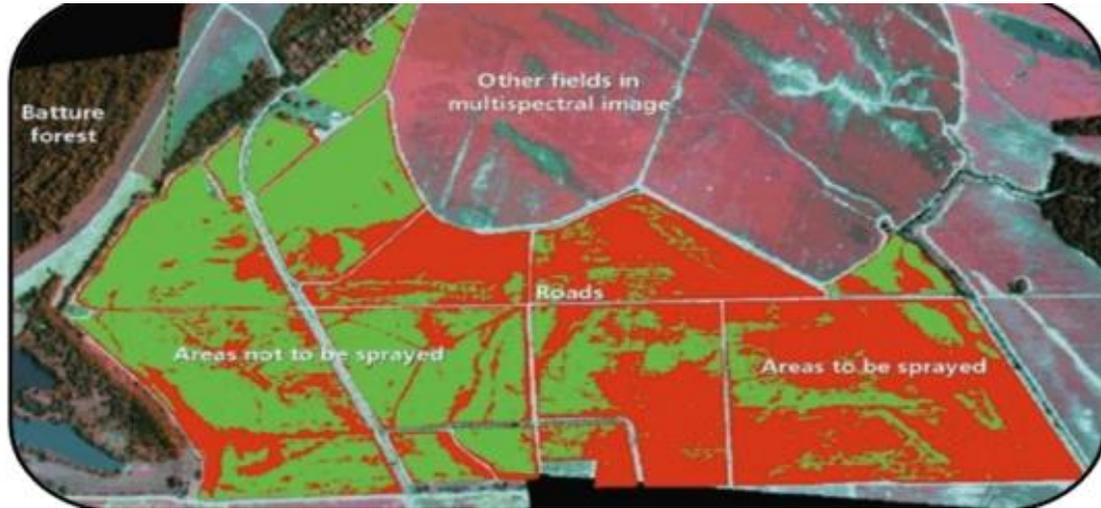


**Figure 4. Thermal sensing of a) True-color image (RGB) of an infected tree, (b) a thermal image of an infected palm tree. Adapted from Ahmed et al., 2019.**

### Fluorescence

Chlorophyll fluorescence is a valuable non-invasive method for assessing the activity of photosystem II (PSII), which can be affected by various abiotic and biotic factors (Baker, 2008; Murchie and Lawson, 2013). In the field, active fluorometric sensors enable the monitoring of disease progression, while passive sensors capture sunlight-induced fluorescence (Aasen et al., 2019; Pinto et al., 2016). When plants get infected, their photosynthetic machinery is compromised, leading to chlorophyll degradation and disruption of the electron transport chain as well as the enzymes in the Calvin cycle. These pathogen-induced changes in the electron transport process can result in pre darkening of the leaves. Advanced chlorophyll fluorescence systems equipped with integrated pulse-amplitude modulation (PAM) and image analysis techniques allow for the quantification of affected leaf areas, which aids in phenotyping efforts (Rousseau et al., 2013; Rousseau et al., 2015). For example, fluorescence spectra have proven effective in identifying brown rust in wheat tissues just four days after inoculation (Tischler et al., 2018). In these studies, the fluorescence quotients showed a correlation with the levels of polyphenols and fungal DNA in the infected leaves. Different light sources, including LEDs, lasers, and sunlight, can induce fluorescence spectra (Bellow et al., 2013). Similarly, researchers examined the responses of resistant barley genotypes to *Blumeria graminis f. sp. hordei* by studying photosystem II quantum yield and non-photochemical quenching parameters (Brugger et al., 2018). While chlorophyll fluorescence responds to initial physiological changes, it has limitations in diagnostic applications because both biotic and abiotic stresses can similarly influence photosynthetic electron transport.

Additionally, the spatial distribution of symptoms at the leaf and plant levels is often irregular, which may lead to confusion with damage caused by arthropod pests.



**Figure 5. Multispectral Mapping of Mississippi River delta-most probable areas of aphid attack in wheat. Highly infected areas indicated in red colour, requires Pesticide application. Image adapted from Sudha Rani et al., 2018.**

### **Hyperspectral Sensing**

Hyperspectral sensing stands out as a crucial method for monitoring plant stress without causing any harm. This technique relies on passive remote sensing, analyzing the solar radiation that plants reflect to glean rich spectral data (Jones and Vaughan, 2010). The information gathered is transformed into what we call a “spectral cube,” providing a comprehensive view of the plant’s condition. By capturing subtle changes in spectral reflectance related to absorption or scattering, this method can identify early signs of physiological issues that may arise from pathogens. Thanks to its high spectral resolution, hyperspectral imaging can create intricate “signatures” for soils, crop canopies, or individual leaves, making it possible to detect even the slightest physiological or biochemical alterations. This capability empowers us to assess stress conditions accurately and promptly. Hyperspectral imaging can be utilized in detection of seedborne pathogens as well (Ferreira et al., 2024. Detecting diseases and pest infestations at an early stage through hyperspectral sensing (Terentev et al., 2022) not only helps avert significant yield losses but also facilitates more targeted pesticide applications. This leads to decreased chemical use, benefiting both the environment and human health (Lucieer et al., 2014; Gonzalez-Dugo et al., 2015).

### **Electronic Nose**

When plants face attacks from pathogens and pests, they respond by releasing volatile organic compounds (VOCs) (Cardoza et al., 2002). Even healthy plants produce these volatile compounds, which are crucial for their growth, communication, defense, and overall survival (Baldwin et al., 2006). Additionally, abiotic stressors can impact VOC emissions, leading to complex mixtures that not only vary in composition but also display unique temporal patterns in natural atmospheric conditions. Electronic noses (e-noses) are designed to detect some of these VOCs through gas chromatography or specialized e-sensing devices. However, it’s important to note that VOC-based detection can often be nonspecific; different diseases may trigger similar

VOC profiles across various plant species, resulting in overlapping compounds. This means it isn't always reliable in distinguishing between plant diseases, pests, and physical damage. The advantages of VOC-based monitoring include its operational simplicity, nondestructive sampling methods, and the capability to capture bulk emissions. Yet, the approach does come with limitations, such as lower sensitivity and specificity when compared to traditional microbiological and molecular diagnostic techniques (Cellini et al., 2017).

### **Advantages of Remote Sensing in Plant Pathology**

- **Monitoring and Forecasting**

Precise monitoring of plant diseases is possible with remote sensing techniques. These techniques are so vivid that asymptomatic infections can also be detected much prior to the onset of disease, hence disease forecasting becomes more effective in plant disease management.

- **Reduce the usage of Fungicides**

Disease forecasting before the onset of disease reduces the application of fungicides and pesticides and hence environmental pollution could be avoided.

- **Large areas of farmland could be studied**

Large areas of cultivation can be studied using remote sensing for detection and monitoring of plant disease.

- **Prediction of climatic changes and other abiotic factors**

Remote sensing can help in predicting the climatic changes and other environmental factors with more accuracy and precision, which can be useful in plant disease management.

### **Disadvantages**

- **Data Accuracy and Resolution**

Precise data and high-resolution images are required to detect physiological changes in the healthy and diseased plant

- **Misleading Data**

Any abiotic and certain physiological change can also indicate a shift in Fluorescence imaging and Volatile organic compounds emitted by the plants. Hence some of the remote sensing methods cannot be reliable.

- **Cost of implementation**

The cost of implementing the sensor devices for small farms is considerably higher and hence cannot be used by all farmers

- **Data Interpretation**

Remote sensing data requires expertise personally for interpreting and analysing the data. Collaboration between technologists and agriculturists can help in knowledge sharing.

- **Data Security and Privacy**

The collection and Ethical use of data causes concern over privacy and security of data that is obtained. Regulations are required to safeguard important data that is obtained through remote sensing.

### **Conclusion**

There are various remote sensing techniques available for detecting and identifying plant diseases. While chlorophyll fluorescence and thermographic methods are highly sensitive to changes in plant metabolism caused by pathogens, they often fall short in distinguishing between biotic and abiotic factors, as well as damage from arthropods. On the other hand, combining spectral data with spatial information from imaging

systems, along with analyzing the volatile organic compounds (VOCs) emitted by affected plants, presents a more promising approach for accurately identifying and classifying diseases. Even though their diagnostic specificity is limited, thermography and fluorescence still serve as valuable tools for monitoring crops. Incorporating additional sensors can further improve the sensitivity of remote sensing platforms. Furthermore, there is an urgent need for knowledge regarding the spatial distribution and incidence of diseases in fields to optimize detection strategies and enhance precision crop management.

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