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INVITED ARTICLE

Unveiling the Potential of Unmanned Aerial Vehicles (UAVs) in Precision Agriculture: An Overview

ABSTRACT

Precision Agriculture (PA) relies heavily on advanced tools and technologies to monitor soil and crop variability both within and between fields. By employing site-specific management, this approach aims to optimize agronomic inputs and achieve higher productivity. The integration of Remote Sensing (RS) technology marks a crucial juncture for PA, propelling the adoption of Variable Rate Technology (VRT). RS technology provides essential spatial input metrics, such as soil nutrients, crop conditions, weed and disease infestations, and yield, among other things. These measures facilitate the implementation of site-specific input application rates, a fundamental goal of the PA. Farm management is aided by various technologies, each with its own advantages and disadvantages. Ground-based proximal RS systems are confronted with accessibility and coverage scale limitations, while satellite systems are confronted with issues such as cloud cover and coarse resolution. In contrast, unmanned aerial vehicles (UAVs) remote sensing offers a promising solution, potentially surmounting the constraints of ground-based and satellite RS. UAVs are a preferred choice due to their exceptional resolution, detailed vegetation insights, multi-angle observations, and growing acceptance among the research community and industry stakeholders. However, the use of UAVs in agriculture is still a costly investment, especially for small farmers, which makes it inaccessible to them. Moreover, the absence of a standardized method or workflow for the use of UAVs in precision agriculture deters their widespread adoption. This article provides an overview of the advancements and potential applications of UAV in precision agriculture, while highlighting the obstacles to widespread adoption.

***Keywords**: Precision agriculture, remote sensing, unmanned aerial vehicle, sensors*

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Agriculture is a cornerstone of human livelihood and faces major challenges related to global environmental conditions. Sensitivity of agricultural products to environmental factors requires accurate information in real time to help farmers understand the cause of variability. Precision agriculture (PA) is becoming a research focus that aims to optimize inputs, boost crop productivity, and minimize environmental impact by executing targeted actions at precise rates, intensities, locations, and times (Velusamy *et al.,* 2021). PA involves field zoning and custom treatments based on landscape, soil, and past practices. However, manual implementation of PAs is labour intensive, which encourages the integration of technology to address these challenges (Maes and Steppe, 2019). Significant strides in agriculture have been made by technological advancements. Despite this, conventional approaches are still common in areas such as soil and crop analysis, precision agriculture, and quality control. While remote sensing has seen extensive use in defense, its potential in agriculture remains largely untapped. Agricultural technologies such as variable rate technologies (VRT), grain yield monitors, global positioning system (GPS), sensor networks, and remote sensing (RS) in PA have gained importance in recent years (Mani *et al.,* 2021).

The remote sensing (RS) provides real-time information on crop and soil properties, facilitating informed decisions for effective crop and land management. This method is a reliable, rapid, and cost-effective way to monitor and analyze agricultural fields on a large scale, which is not possible through traditional surveys. The RS encompasses various bands of electromagnetic radiation, including visible, near infrared (NIR), short-wave infrared (SWIR), thermal infrared (TIR) and microwaves. Precision farming relies on ground-based robotics and satellite/aerial RS, which enable mapping of field variability, monitoring of water stress, nutrient status, plant cover, pests, diseases, and more (Piikki *et al.*, 2022). However, challenges remain, such as inaccessibility in difficult terrain, coarse spatial resolution, significant revisiting time, and cloud cover. The preferred solution is aerial systems like Unmanned Aerial Vehicles (UAVs), which can fly under clouds and provide very high-resolution images.

Unmanned Aerial Vehicles (UAVs) have become an inexpensive alternative to monitoring crop conditions in real time. UAVs have been identified in previous studies as a potential alternative to satellite and airborne remote sensing in precision agriculture. UAVs provide detailed images, which aid in timely crop, trait monitoring, stress assessment, and health analysis. By producing 3-D maps and models, UAVs facilitates field planning, drainage and yield prediction. The targeted input application is enabled by them, which reduces waste and costs while optimizing irrigation and pest management. Real-time data aids in informed decision-making, improving productivity, resource efficiency, and sustainable farming practices. These are small, reusable remote control vehicles that can generate high-resolution images. UAVs are controlled by radio or smartphone to capture various images using different sensors to meet PA requirements (Nhamo *et al.,* 2020). These sensors provide valuable 2-D data with GPS coordinates or live video at ground stations (Maes and Steppe, 2019). The potential of UAVs to enhance soil quality and crop productivity in precision agriculture is significant. Figure 1 gives an overview of the data acquisition process and how it works in the PA system, while figure 2 depicts certain applications in the crop monitoring experiment. This review outlines the types of UAVs, technical specifications, challenges and future prospects of UAV remote sensing in precision agriculture.

COMPONENTS OF UAVs IN PRECISION AGRICULTURE

The components of UAV-based precision agriculture refer to the various essential elements that come together to facilitate data collection, analysis, and decision-making. The physical UAV platform, sensors, communication systems, navigation tools, data processing software, and more are included in these components. The UAV system's overall functionality is aided by each component, which results in optimized resource management and increased crop productivity. The essential components are:

UAV Platform

The physical aircraft itself, equipped with the requisite propulsion systems (rotors or fixed wing), flight control systems and communication devices. The UAV is the carrier for various sensors and payloads. The assigned task or application has led to the development of a vast range of UAVs. UAV systems can be classified by weight, number of rotors, size, power, load, mechanism, objective, etc. through various classification systems (Table 1) (Singhal *et al.,* 2018).

Table 1: Classification of UAVs and their characteristics

Category	Types	Characteristics
Aerodynamics	Fixed wing	• The main wing that generates lift is fixed and the power device supplies the forward force • Simple in design • Requires higher starting velocity and higher drag lift ratio. *Limitations* • Cannot maintain fixed position and slow speed • Design saturation
	Rotary wing	• The blade rotates relative to the fuselage and power devices generates lift • Capable of having vertical flight which facilitates takeoff and landing • Further classified as a single rotor and multi-rotor UAV *Limitations* • Low flight stability against wind and low speed
	Flapping wing	• Obtain lift and power by flapping wings up and down • Ideal for small, light and miniature UAVs • Flexible, lightweight and can withstand flights in windy conditions
	Hybrid wing	• Fusion of two of the above-mentioned wings, i.e. Fixed-rotor wing and fixed-flapping wing UAVs • Have higher performance and aerodynamic advantages
Take-off and Landing	Horizontal takeoff and landing (HTOL)	• HTOL has a smooth landing and a high cruising speed
	Vertical takeoff and landing (VTOL)	• VTOL has a low cruising speed
Weight	Super Heavy	• Payload size: 2500 kg • Operation range: 1500 km
	Heavy	• Payload size: 2000 kg • Operation range: 1000 km
	High Altitude Long Endurance (HALE)	• Payload size: 1000 kg • Operation range: 250 km
	Medium Altitude Long Endurance (MALE)	• Payload size: 1000 kg • Operation range: 200 km
	Light	• Payload size: 50 kg • Operation range: 70 km
	Small & Mini	• Payload size: 20 kg and less • Operation range: 40 km
	Micro & Nano	• Payload size: 2 kg - 200 gm • Operation range: 25 - 5 km

Sensors

To capture information about crops, soil, environmental conditions, and other relevant factors, various sensors are attached to the UAV. The selection of sensors in PA is based on the application. For motion-intensive tasks like large land mapping, global shutter cameras are favored over rolling shutters due to their single-snapshot scene capture that reduces motion artifacts. The frame rate is crucial; higher rates increase resolution and coverage, which is crucial for image stitching. The Field Of View (FOV) plays a crucial role in monitoring between crop aisles and detecting shaded weeds. Ground Sampling Distance (GSD) determines the resolution by measuring sensor height and pixel count. Optical sensors with visible bands and NIR are preferred for assessing crop health based on vegetation, whereas thermal sensors are suitable for dense canopies. Sensor choice in precision agriculture is influenced by these factors (Zhang and Zhou, 2016). Table 2 below gives a brief description of the products that are most commonly available in the market.

Table 2: Various sensors and their properties

Type	Characteristics	Limitations
Red-Green-Blue (RGB) sensors	• Utilizes the red, green, and blue wavelengths to capture image • Cost-effective, high spatial resolution images, easy to use, and light weight • Simple information processing • RGB indices provide more precise information	• Lacks detailed spectral information
Multispectral sensors	• Capture images in multiple bands of the electromagnetic (EM) spectrum • Offers spectral data for advanced vegetation analysis, crop health assessment, and stress detection • Being more sensitive, stable over time, and independent of weather conditions	• Limited spectral resolution • Complex data interpretation and expensive • Generate a large amount of data that needs suitable infrastructure and resources.
Hyperspectral sensors	• Capture data in numerous narrow and contiguous spectral bands • The spectral resolution is ultra-thin, provide much more detailed and unfettered information • Effective in identifying mineral composition and soil properties, aiding in soil fertility assessment and precision nutrient management.	• Require sophisticated analysis techniques • Expensive to develop, purchase, and maintain
Thermal sensors	• Captures infrared radiation emitted by objects • Identifies temperature anomalies, useful for detecting stress, evaluating irrigation efficiency and detecting water leakage. • Recommended to detect temperature-induced water stress in crops	• Good atmospheric conditions are necessary, especially for specific tasks like thermal analysis.

Payloads

The packages are complete and contain sensors, as well as other necessary equipment (such as power supplies, data storage devices, and communication systems) for data collection and processing. An RGB camera, a multispectral sensor, a GPS unit, and an onboard computer for data processing could be included in a payload for crop health assessment (Maes and Steppe, 2019).

Data Storage and Processing

Managing and utilizing valuable information collected during UAV flights requires effective data storage and processing. UAVs gather diverse data, including images, videos, sensor readings, and telemetry, necessitating proper storage mechanisms to facilitate subsequent analysis. Onboard storage, matching mission requirements for storage capacity, and wireless data transfer methods contribute to efficient data management. Also, processing the data collected is essential to obtaining actionable information. UAVs generate vast datasets which require specialized software and algorithms for interpretation. It covers image enhancement, geo-referencing, remote sensing analysis, machine learning, map generation, data fusion, storage, archiving and even real-time processing (Marchi *et al*., 2022). Farmers and stakeholders can make informed decisions, enhance crop management, and optimize agricultural productivity through the conversion of raw data into actionable intelligence through the use of these components.

Ground Control Station (GCS)

The GCS is a computer-based interface where the UAV is operated and monitored. The system consists of hardware (such as a remote controller or computer) and software interfaces that enable operators to plan flights, control the UAV, receive data, and visualize collected information.

Data Processing Software

Software is critical to planning, flight paths, controlling the UAV, processing the collected data, and generating actionable data. A flight planning software assists in defining routes, waypoints and other flight parameters. Data processing software transforms collected data into usable information, like maps or 3D models (Mani *et al.,* 2021).

APPLICATIONS

To improve crop yields and product quality without any unnecessary environmental impact, PA relies on effective and accurate Agrochemicals and technologies, as previously discussed. The low-cost, high-resolution imaging offered by UAVs has been a perfect addition to the PA industry and the most widely used for monitoring and agrochemical spraying (Liu *et al.,* 2021). In this section, we discussed some of the most common UAV applications in PA systems, such as:

Water Stress Detection

Precision irrigation primarily aims to optimize the use of water resources and prevent crop stress due to water scarcity. It also reduces problems such as soil salinity, acidity, nutrient leaching, water logging in lowlands and droughts in uplands. An effective strategy for this involves evaluating crop water stress indices, enabling the early identification of drought stress, often up to 24 to 48 hours before it becomes visually apparent (Marchi *et al.,* 2022). To estimate stomatal conductance based on temperature data, UAV-assisted thermal imaging utilizes the decrease in leaf or plant surface temperature during transpiration (Maes and Steppe, 2019). By using UAVs, field monitoring of water stress can be improved, leading to improved irrigation scheduling. The accuracy of crop water stress assessment has been increased by the integration of thermal and multispectral UAVs compared to space-borne remote sensing due to high resolution (Nhamo *et al.,* 2020). Moreover, hyperspectral sensors offer vegetation indices like NDVI and sun-induced fluorescence (SIF) to detect moisture stress, albeit with a slightly lower sensitivity than thermal indices.

Weed Detection and Mapping

Weeds pose a significant threat to agricultural productivity, potentially leading to substantial yield losses or even crop failure. To prevent environmental harm, it is important to apply herbicides appropriately and responsibly. Therefore, accurate identification of weed areas, types and densities is critical for targeted herbicide application or specific cultural interventions (Marchi *et al.,* 2022). By using UAV sensors like RGB, multispectral, and hyperspectral, weeds can be detected and their distribution can be mapped. For instance, Goel et al. (2002) identified spectral bands in the red and near-infrared regions that effectively discriminate weedy areas from non-weedy ones. The key factors are achieving up to 91% accuracy in weed identification, high spatial resolution, and low elevation (**Fig.2**). The use of spectral discrimination in site-specific weed management resulted in a significant reduction in the time required for weed identification and herbicide use, without affecting crop performance (Maes and Steppe, 2019).

Pest and Disease Detection

Pest and disease infestations that are below the economic threshold can have an impact on product quality, if not on crop performance. UAV imagery facilitates early detection of pests and diseases, enabling precise pesticide application and reducing costs and environmental impact (Marchi *et al.,* 2022). Site-specific pesticide management involves pinpointing infected areas accurately based on spectral discrepancies. To gather detailed information, low-level flights and high-resolution/spectral sensors are essential (Liu *et al*., 2021). To gather detailed information, low altitude flying and high resolution/ spectral sensors are essential. Hyperspectral images are better at early detection and discrimination, while multispectral images are more susceptible to false negatives. Spectral reflectance is unique due to changes in leaf chemistry and structure caused by pathogens, making hyperspectral and thermal data combinations valuable for early disease identification (Velusamy *et al.,* 2019).

Growth and Biomass Monitoring

UAV aids farmers in tracking crop growth indicators like seedling status, growth stage, and biomass, which is essential for maintaining crop health, preventing nutrient deficiencies, yield analysis, and policy formulation. Biophysical and biochemical properties, such as crop height, can be accessed through vegetation indices derived from multispectral/ hyper-spectral sensors mounted to UAV (**Fig.2**), leaf area index, nitrogen content, and more. Structure-from-motion (SfM) software provides precise vegetation height data and is superior to LIDAR for precision agriculture, although it's limited when soil is concealed. By combining vegetation height with other indices, the biomass above ground is estimated (Marchi *et al*., 2022).

Yield Estimation

Accurate yield estimation is essential for efficient stock planning and gentle harvesting. UAV remote sensing provides a nondestructive way to predict crop yield through morphological observation. Cost, cloud interference, and land heterogeneity limit high-resolution satellite images. UAVs equipped with multimodal sensors — hyperspectral/multispectral, thermal infrared, and combinations with RGB or SAR — provide consistent and accurate data for yield prediction (Liu *et al.,* 2021). The correlation between high-resolution UAV-derived vegetation indices and green biomass and yield makes them reliable predictors. Yield forecasting facilitates timely preparation for crop shortages or surpluses. Empirical statistical models, water consumption balance models, and biomass estimation models are the three primary RS models for yield estimation (Velusamy *et al.,* 2021). To evaluate genetic variation's impact on crop development and yield potential, plant height and biomass are crucial, which is crucial for tailored crop management and yield projections (Liu *et al*., 2021).

Soil Monitoring

Central to precision agriculture, crop sensors determine variable fertilizer application rates. Plant nutritional status can be effectively assessed using hyperspectral UAV imagery. Real-time variable fertilizer rate recommendations can be provided by various commercial multispectral systems by leveraging the connection between plant reflectance and nutritional status (Piikki *et al.,* 2022). Hyperspectral data provides superior results compared to multispectral sensors, but it relies on empirical models that are specific to the location and season. By computing various reflection input parameters, radiation transfer reversal models can circumvent this limitation (Fenghua *et al.,* 2017). UAV imagery has advantages over satellite imagery in terms of vegetation height estimation and diverse viewing angle perspectives.

Frost Detection and yield prediction

In many parts of India, crops are frequently damaged by frost, resulting in poor yields or even complete crop failure. Dry air on windless nights under clear skies has also seen an increase in hoar frost.

However, frost is often local and unpredictable, and since it occurs at night, it can be overlooked. Furthermore, the damage it causes to a crop may go unnoticed for a week or more, after which it becomes apparent that the crop will not recover. In this regard, UAVs or low-flying drones can play an important role in the early detection and quantitative assessment of the loss of photosynthetic potential of gel-damaged crops. Monitoring crop conditions, mapping damaged areas, managing crop recovery, and predicting the yield of damaged fields may also be possible using the UAV (Choudhury et al., 2019). As both multispectral cameras and UAVs become cheaper, farmers should be able to afford them to monitor their crops and assess any damage caused by frost quickly. The quick and high resolution damage area mapping (Fig.2) ability of the UAV can be utilized for settling crop insurance claims in a similar manner.

LIMITATION AND FUTURE RESEARCH DIRECTIVES ON UAVs

The adoption of UAVs is accompanied by several constraints. Small-scale farmers cannot access them due to the substantial investment required for their use in agriculture. The lack of standardized workflows has led to informal practices that discourage other potential stakeholders. Data collection and processing involves complex computations, requiring specialized training or expert engagement, thereby increasing costs. Low-cost UAVs also has certain disadvantages, such as reduced dimensions, stability, flight altitude, and image quality. In addition, short flight times, flexible flight schedules, the complexity of repeated measurements, and vulnerability to weather conditions limit their effectiveness. Additional challenges are posed by safety, security, and regulations.

UAV implementation in Precision Agriculture is still in its infancy, but it shows the potential for advancement in applications and technology. The rapid advancements in UAV technology will result in a reduction in sensor and data processing costs for years to come. However, there is a great deal of promise in enhancing the flight duration and stability. Addressing the shortage of algorithms for precise vegetation analysis and automated anomaly detection is crucial. The integration of multiple sensors is essential for superior soil and vegetation monitoring, which minimizes post-harvest losses and pest and disease threats to maximize profitability by reducing input costs, specifically fertilizer. The next phase is the construction of real-time decision support systems. Developing a more proficient, a standardized data acquisition methodology based on crop phenological stages is vital for precision.

This article aims to give a comprehensive overview of the use and significance of UAVs in precision agriculture. UAV technology is widely accepted as an efficient and robust method for obtaining information to increase productivity and economic gains on a sustainable basis. Although it is a costly investment, it ensures a good return. Its practical application still presents a variety of critical challenges, such as platform reliability, flight time, analytics software, and lack of standard operating procedures. Another obstacle is the challenge of analyzing and interpreting information. Familiarization of this technology with farmers and smallholders is necessary for full exploitation and implementation. It is predicted that with continued and rigorous development, improvements in platform technology, camera design, and image processing techniques will result in cost reduction.

LITERATURE CITED

Choudhury B U, Webster R, Sharma V, Goswami J, Meetei T T, Krishnappa R and Raju P L N 2019. Frost damage to maize in northeastern India: detection and assessment by hyperspectral proximal remote sensing. *Journal of Applied Remote Sensing*, 13(4): 044527.

De Marchi M, Diantini A and Pappalardo S E 2022 *Drones and Geographical Information Technologies in Agroecology and Organic Farming: Contributions to Technological Sovereignty. 1st ed.,* Taylor & Francis, Abingdon, Oxon, 308 pp.

Goel P K, Prasher S O, Patel RM, Smith D L and DiTommaso A 2002 Use of airborne multi–spectral imagery for weed detection in field crops. *Transactions of the ASAE,* 45(2): 443.

Figure 1: Schematic representation of the synergy between UAVs and precision agriculture.

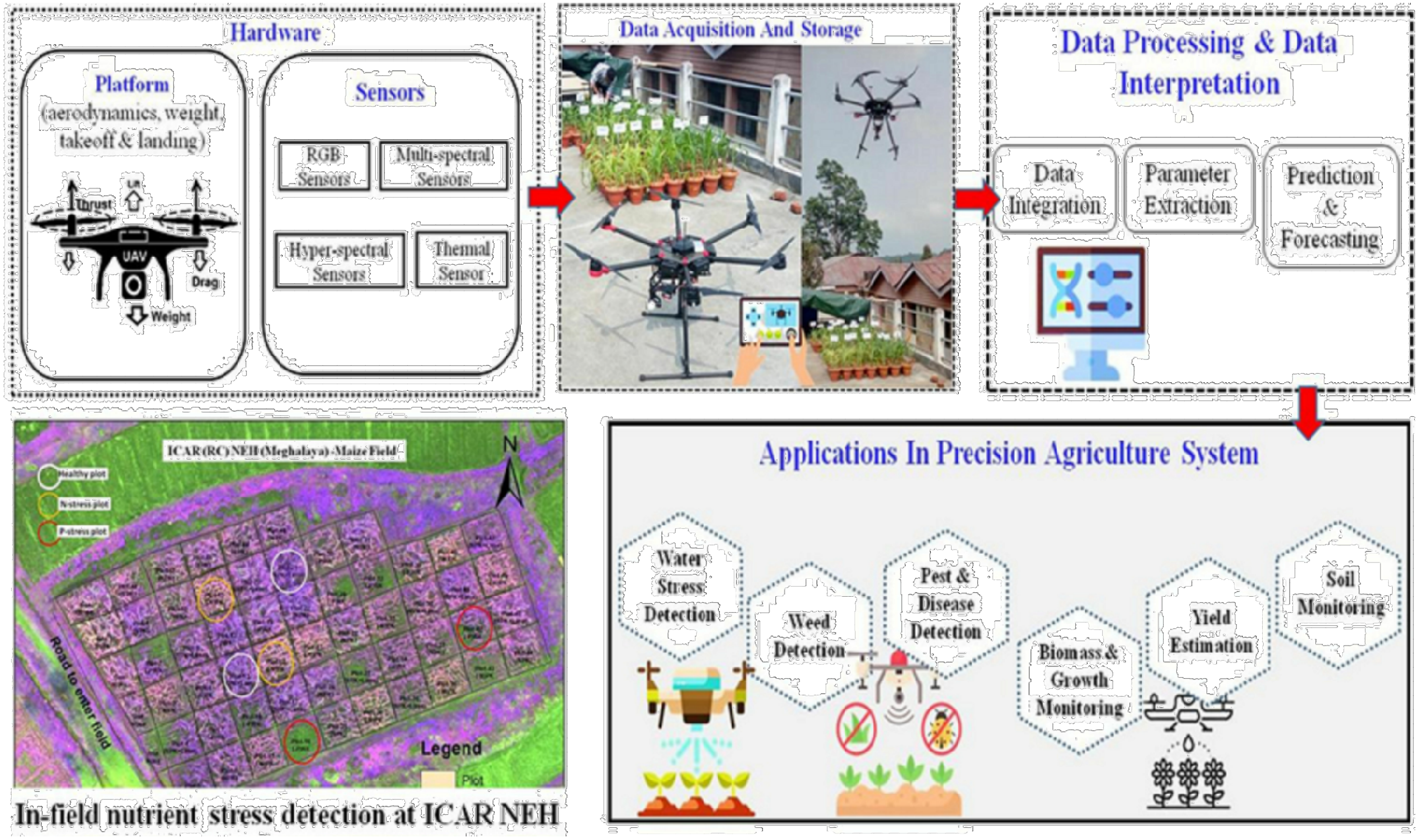
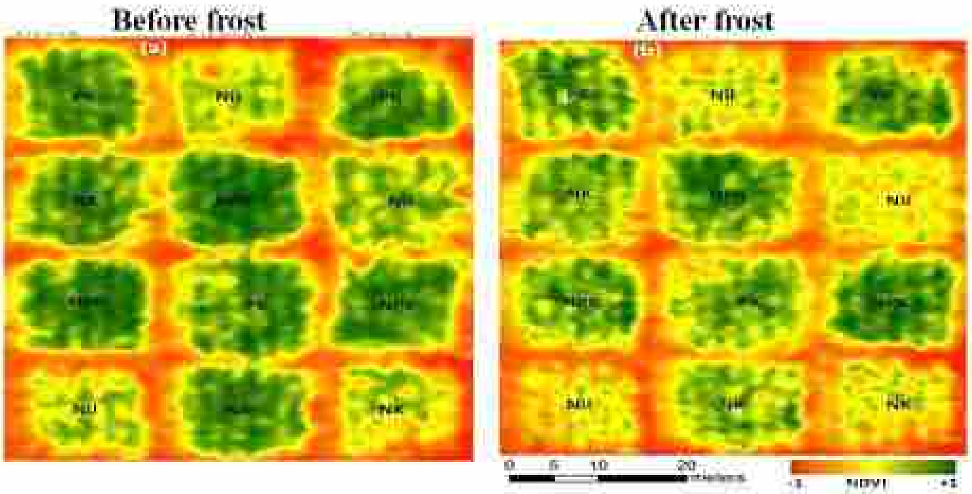


Figure 2: The application of multi-spectral UAVs for crop (e.g. Maize) growth and health assessment activities, including detection of frost damage at ICAR RC in NEH Region, Umiam, Meghalaya

Periodic crop growth monitoring using multi-spectral UAV at ICAR RC for NEH, Meghalaya

Mapping and area estimation of crop field at ICAR NEH

Maize height determination from UAV image



Extent of damage of maize crop by frost (yellow colour)

Liu J, Xiang J, Jin Y, Liu R, Yan J and Wang L 2021 Boost Precision Agriculture with Unmanned Aerial Vehicle Remote Sensing and Edge Intelligence: A Survey. *Remote Sensing*, 13(21): 4387.

Maes W H and Steppe K 2019 Perspectives for remote sensing with unmanned aerial vehicles in precision agriculture. *Trends in plant science*, 24(2): 152-64.

Mani P K, Mandal A, Biswas S, Sarkar B, Mitran T and Meena R S 2021 Remote sensing and geographic information system: a tool for precision farming. *Geospatial Technologies for Crops and Soils*: 49-111.

Nhamo L, Magidi J, Nyamugama A, Clulow A D, Sibanda M, Chimonyo V G and Mabhaudhi T 2020 Prospects of improving agricultural and water productivity through unmanned aerial vehicles. A*griculture,* 10(7): 256.

Piikki K, Söderström M, Stadig H and Wolters S 2022 Remote sensing and on-farm experiments for determining in-season nitrogen rates in winter wheat–Options for implementation, model accuracy and remaining challenges. *Field Crops Research*, 289: 108742.

Singhal G, Bansod B and Mathew L 2018 Unmanned aerial vehicle classification, applications and challenges: A review. Preprints 2018, 2018110601.

Velusamy P, Rajendran S, Mahendran R K, Naseer S, Shafiq M and Choi, J G 2021 Unmanned Aerial Vehicles (UAV) in precision agriculture: applications and challenges. *Energies,* 15(1): 217.

Zhang D and Zhou G 2016 Estimation of soil moisture from optical and thermal remote sensing: A review. *Sensors*, 16(8): 1308.