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APPLICATION OF PHOTOGRAMMETRIC TECHNOLOGIES FOR CROP MONITORING IN PRECISION AGRICULTURE

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Abstract

This article examines the application of modern photogrammetric technologies for crop monitoring in the context of precision agriculture. Effective assessment of crop condition and spatial variability remains a critical challenge for improving productivity and optimizing resource use in large and heterogeneous agricultural areas. To address this issue, the proposed methodology employs unmanned aerial vehicles equipped with a high-resolution camera, combined with structure-from-motion photogrammetric processing, to generate detailed orthomosaics and crop surface models. Vegetation indices and canopy metrics are derived to support spatial analysis of crop vigour and growth patterns throughout the growing season. The study evaluates alfalfa fields located in the agricultural area surrounding Alba Iulia, employing UAV-based photogrammetry to quantify crop surface characteristics. The workflow generated a high-density point cloud and a high-precision 3D surface model, enabling detailed assessment of canopy structure and health and spatial variability. The results provide the basis for monitoring crop condition, support future analysis of field parameters, and demonstrate that photogrammetric products enable timely and accurate detection of stress conditions, biomass variability, and development anomalies at field scale. The study confirms that modern photogrammetric techniques provide a reliable, cost-effective, and scalable solution for supporting data-driven decision-making in crop monitoring and management.

Key words: *crop monitoring, photogrammetry, precision agriculture, unmanned aerial vehicles, vegetation indices.*

INTRODUCTION

The field of global agriculture is currently facing some significant challenges, which are, first of all, due to increasing climate changes. These challenges include extreme weather, such as droughts, and pests that are affecting more than half of farmland (FAO, 2017). Besides these challenges, there are also degradation factors, like soil degradation, which is affecting a significant part of the land (FAO, 2017). Also, other significant challenges must be considered, including but not limited to water scarcity and, therefore, the rising input costs. These factors pose a threat to food security, worsening the economic instability, and it is required the implementation of urgent, sustainable, and technologically innovative farming solutions to support a growing global population. Climatic events, such as floods and droughts, may be the causal factors for crop production disruption. Furthermore, a significant part of agricultural land is subject to severe soil degradation, declining the productivity. The rapid depletion of natural resources, including water shortages for irrigation, can reduce long-term viability. The necessity to nourish a growing population correlated with diminishing land availability for agriculture is exerting considerable pressure on global food systems (FAO, 2017). Geopolitical tensions and recurring logistical constraints, such as maritime grain export disruptions or rising energy and fuel prices (International Food Federation, 2025) have, in recent years, placed additional pressure on the stability of food distribution systems. Addressing these challenges is not straightforward and typically involves a gradual shift away from purely conventional agricultural practices toward more sustainable approaches, such as agroecology and climate-smart agriculture, combined with the selective adoption of modern technologies aimed at improving system resilience (FAO, 2017).

Against this background, precision agriculture has attracted increasing interest within the agricultural sector. In general terms, the

concept refers to a data-informed approach to farm management that makes use of technologies including GNSS positioning, environmental sensors, unmanned aerial vehicles, and artificial intelligence. Used appropriately, these tools allow continuous monitoring and support more targeted responses to variability both within individual fields and across different fields. This management approach is characterized by a transition from a uniform, large-scale application to a precise, site-specific management strategy. This strategy enhances efficiency, sustainability, and profit. The following elements constitute the fundamental components of the precision agriculture paradigm (Todmal, 2023; Gulaiya et al., 2024):

- The collection is to be undertaken using a variety of methods, including GNSS, GIS, photogrammetry, remote sensing (via drones and satellites), and soil sensors. The purpose of this data collection is to obtain information on soil moisture, nutrient levels, and crop health.
- The data analysis is conducted through the assessment of yield maps and spatial variability data, with the objective of identifying areas of underperformance or specific, localized needs.
- Variable rate technology involves the use of automated equipment for the application of fertilizers, pesticides and water at varying rates across a field, with the objective of customizing the application to specific requirements as opposed to employing a uniform, average rate.
- The implementation of guidance systems, utilizing GPS-enabled machinery in tasks such as planting and spraying, has been demonstrated to reduce overlap, leading to significant savings in fuel and resources.

Conventional field scouting and photogrammetric monitoring both have distinct, often complementary limitations. Whilst field scouting is constrained by human labour and time, photogrammetric monitoring using UAVs is restricted by environmental, technical and data processing bottlenecks. Conventional, manual scouting involves physical inspection by professionals, which introduces several limitations: the processes under discussion are characterized by their labour intensity and time consumption, the presence of subjectivity and human error, their limited spatial coverage, physical inaccessibility, and delayed action. On the other hand, photogrammetry, the process of creating 3D models and orthophotos from drone images, provides high-resolution data, but is also subject to several limitations: the factors to be considered include weather and lighting dependency, visibility and occlusion issues, textureless/uniform surfaces, data processing bottlenecks, reduced vertical accuracy, regulatory and skill barriers. In order to address these issues, contemporary agriculture practices frequently employ a combination of both approaches, leveraging photogrammetry to identify areas of concern and subsequently conducting targeted, ground-based manual verification (Kalischuk et al., 2019; Amarasingam et al., 2022).

Photogrammetric technologies are increasingly used in agriculture, most often through aerial imagery collected by unmanned aerial vehicles (UAVs). The resulting products - such as three-dimensional models, orthomosaics, and elevation data - provide valuable spatial information that supports the adoption of precision farming practices. In current applications, these tools contribute to high-throughput phenotyping, crop condition assessment (frequently based on vegetation indices such as NDVI or other multispectral datasets), as well as to the early identification of pest presence and the optimization of irrigation management. This way, targeted resource application is enabled. There are some technologies of particular significance: unmanned aerial vehicles (UAVs), specialized software and artificial intelligence (AI). These technologies provide detailed, actionable insights within a time frame, usually of several hours, which represent an important advantage in crop security (Delgado Vera et al., 2017; Turlea et al., 2023; Dreghici et al., 2024).

There should be mentioned the following key applications in the agriculture field (Delgado Vera et al., 2017; Sakthivel et al., 2025):

- Crop monitoring and health assessment, by using photogrammetry for the detection of pest attacks, water stress and nutrient deficiencies;
- 3D modelling and mapping, for the analysis of field variability, monitoring of growth patterns and the improvement of terrain management;

- Yield prediction and management, for the prediction of crop production and the optimization of fertilizer and pesticide input usage;
- Precision irrigation and drainage, for the identification of areas with poor drainage or water accumulation;
- Crop management, for the precise, non-destructive monitoring of crop structure and development throughout the season.

The technologies and tools considered in this context include several widely used solutions (Delgado Vera et al., 2017; Turlea et al., 2023; Sakthivel et al., 2025). Among them, unmanned aerial vehicles (UAVs), commonly referred to as drones and typically equipped with GNSS/GPS positioning systems, play an important role by enabling the acquisition of high-resolution imagery suitable for detailed mapping applications. Sensors, which may be multispectral, thermal or RGB, frequently utilised for the collection of data.

- Software, such as the photogrammetric software Agisoft MetaShape, used to process images into orthomosaics and 3D models.
- Artificial intelligence (AI) and machine learning integrated with photogrammetry, for automated analysis of field data.

UAVs represent a viable solution for high-resolution and cost-effective agricultural monitoring and management, being considered a significant advancement over traditional satellite, manned aircraft, and ground-based surveying methods. Unmanned aerial vehicles come with higher spatial resolution, usually at centimetre-level, this way bridging the gap between field-level measurements and satellite imagery. The usage of UAVs reduces time, labour, and financial overhead (typically associated with conventional manual scouting and manned aerial surveys) (Guebsi et al., 2024; Sreenatha et al., 2025).

Two principal research gaps emerge when applying photogrammetric technologies in the context of agricultural monitoring:

- The integration of three-dimensional photogrammetric products, such as crop height models, into routine crop monitoring is inadequate.
- A limited number of comparative studies have been conducted between photogrammetry-derived metrics and traditional agronomic measurements.

In this context, the objectives of the present study are as follows:

- To evaluate the applicability of photogrammetric technologies for the purpose of monitoring crop growth and condition;
- To assess the contribution of precision agriculture in case of decision-making processes;
- To highlight the contribution of photogrammetry in agriculture and its support for the shift toward modern, digital, and sustainable farming, by producing photogrammetric outputs used for agricultural land evaluation and monitoring of land use changes.

MATERIALS AND METHODS

The site chosen for the case study in this paper is located in the peri-urban area of Alba Iulia, in an agricultural area, predominantly used for cereal production. The area's accessibility and terrain with relatively uniform elevation render it conducive to UAV operations. The location has been determined to provide suitability for the application of modern crop monitoring technologies, allowing for efficient data collection with the equipment used. Certain figures and supporting materials used in this paper are adapted from, or were originally presented in, the bachelor's thesis by Pitton, G. (2025), "The use of modern technology in monitoring agricultural crops".

The topography of the studied area is characterised by its relative flatness, with gentle slopes and minimal altitude variations. These characteristics make the area suitable for photogrammetric flights and aerial image acquisition, as well as for generating high-precision 3D models and orthophotos. The soil type is chernozem and luvisol, which is specific to Alba County areas. These soils are moderately permeable and medium to highly fertile, characteristics that are favourable to cereal crops and vegetables.

Data acquisition

The WingtraOne Gen II drone, used for the present purpose, is a technologically advanced aerial mapping equipment, specifically designed for professional applications in the field of land surveying, cadastral mapping,

agricultural monitoring, and environmental management. The flight platform, VTOL-type (Vertical Take Off and Landing) was designed to be robust and to use state-of-the-art technology. This means that it offers remarkable performance in terms of autonomy, accuracy and versatility for aerial photogrammetric applications. Integrating the advanced onboard avionics sensor suite, the autonomous and real-time stability flight-control architecture, and mission-optimized planning environment transformed this aerial platform into a comprehensive solution for the creation of high-resolution orthophotos and 3D models. The drone is equipped with a high-resolution camera, for optimal aerial images acquisition. A further significant feature of the WingtraOne Gen II drone is the incorporation of GNSS RTK/PPK system, which allows direct image georeferencing with high precision, minimising the requirement for a considerable number of ground control points (GCPs).

Mission planning is conducted utilising the dedicated WingtraPilot software, which facilitates precise configuration of flight parameters and optimisation of the trajectory to ensure an overlap that fulfils photogrammetry requirements.

The utilisation of this drone facilitated the effective collection of data essential for the monitoring of existing crops in the vicinity of Alba Iulia, thereby providing decision support in the analysis of agricultural crops and agricultural land management.

The planned flight route is configured to respond the specific terrain conditions, ensuring consistent coverage and data quality, as shown in Figure 1. In the present case study, the decision was taken to fly at a flight height of 120 metres. In order to obtain high-accuracy and high-resolution images, the GSD parameter was set relatively high, 3.2 cm/pixel, as recommended for the specified flight height. In addition, the controller interface provides information about the drone's anticipated flight trajectory, representing the total area to be covered, the status of connectivity with the GNSS signal, the number of satellites that are currently visible, and also the current battery level of the drone.

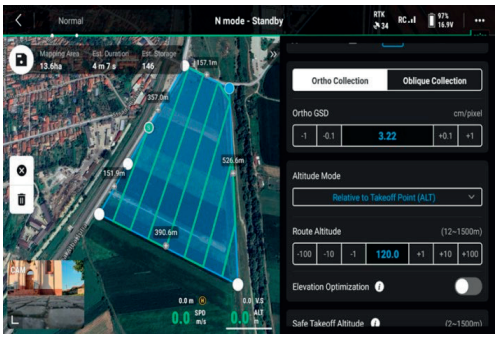


Figure 1. Flight plan

Photogrammetric processing

Upon completion of the flight session in the field and collection of the necessary data for this project, the subsequent stage would involve the transfer of all obtained data to a computer, with the objective of creating a 3D model of the terrain and an orthophoto map.

The Agisoft MetaShape program facilitates data processing through the provision of an integrated, efficient, and precise workflow, thereby ensuring the generation of high-quality geospatial products. The utilisation of this software within the project enabled the conversion of raw images captured by the drone into a series of photogrammetric materials that were conducive to the analysis of agricultural land. The high accuracy of the orthophoto map and the 3D model obtained provides a solid basis for decision-making in precision agriculture, considering the monitoring of crops and agricultural land.

The workflow comprised the following stages:

1. The process of image alignment entails the identification of the position and orientation of images, with the objective of constructing an initial point cloud based on the corresponding points between images, known as tie points. The geometric relationship between images is established through the comparison and overlaying of common features. In accordance with the aforementioned points, the program implements a global bundle adjustment. This adjustment constitutes a mathematical optimization that determines the position and orientation of each image in three-dimensional space. The outcome of this process is a relatively accurate reconstruction of the flight path - Figure 2.

In order to achieve optimal and precise results for the final products, it is imperative to filter the tie points from the previously created point cloud (Figure 3). This is due to the fact that numerous erroneous points will be identified during this process. The quality of subsequent photogrammetric products (i.e. dense point cloud, 3D model, orthophoto map) is contingent upon the quality of the initial list of connection points. Following the filtration of the tie points, it is imperative to utilise the "Optimize camera alignment" function. The purpose of this function is to enhance the precision of photogrammetric reconstruction, after the implementation of adjustments to the tie points.

2. The second fundamental stage of the workflow is the creation of a dense point cloud (Figure 4), using the image alignment results as input. in the present case study, the dense point cloud reconstruction was performed using the ultra-high-quality parameter and moderate depth filtering, selected to balance geometric accuracy with computational efficiency. Applying these settings, there was produced a detailed and spatially consistent dense point cloud, that served as the basis for the subsequent 3D surface model and orthophoto generation.

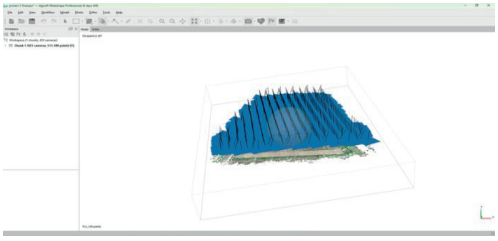


Figure 2. Aligned images along the flight path

The "reprojection error" criterion is another essential indicator of the quality of photo alignment and the accuracy of connection points. This criterion is used for assessing the precision of the reconstructed 3D points and whether they correspond to their projected positions in the source image. This way, the difference between the estimated position of a 3D point projected back onto the image and the actual position of that point detected in the photo is measured. The reprojection error is expressed in pixels. The errors are inversely proportional to accuracy: the smaller the error, the higher accuracy for the point. After this optimisation, the mean error should be reduced significantly, enhancing the project accuracy.

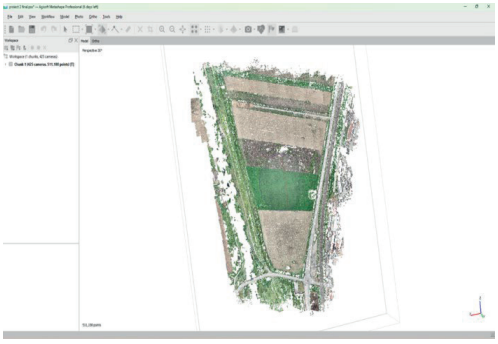


Figure 3. Point cloud

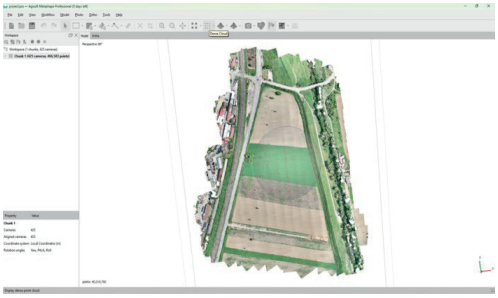


Figure 4. Dense point cloud

3. The third fundamental stage of the project is the creation of the mesh model. The mesh model is a three-dimensional reconstruction of the photographed surface, formed from a network of triangles (polygons) that connect the previously generated points. This stage is of critical importance in the photogrammetric process, as it is the foundation for obtaining a highly detailed model of the terrain or objects under consideration. Furthermore, it facilitates the application of textures and the subsequent measurement of various parameters. For mesh generation, the dense point cloud was used as the primary data source, with the surface type configured for three-dimensional reconstruction.

The "Face count" criterion in the mesh model construction window represents the estimated number of geometric faces that will make up the polygonal network of the 3D model. The

geometric intricacy of the model is directly proportional to the number of facets, but the processing time and hardware resources required increase exponentially.

4. The next stage of the workflow consisted of applying texture to the resulting 3D model in order to enhance its visual realism. The option "Diffuse map" is the type of texture applied to the generated surface of the 3D model to render the terrain colour and natural appearance. This texture is taken from the captured images during the flight. It is imperative to note that this option is essential for realistic rendering of the surface.

Given the approximately flat surface of the project, the decision was taken to utilise the 'Adaptive orthophoto' function, as this projects a texture similar to that of the orthophoto plan. This allows the algorithm to dynamically select the most suitable pixels from the source image set for texture projection onto the 3D model, thus avoiding perspective errors and distortions at the edges of the images.

In considering the objectives set for this project, the decision was taken to construct a tiled model, given the necessity to analyse the monitored crop area in detail. This model offers a more flexible and detailed representation of surfaces and is optimised for viewing 3D structures at different zoom levels and resolutions. The tiled model is based on a hierarchical organisation of spatial data, which allows for the efficient display of fine details such as soil textures, crop damage, uneven vegetation, or traces of agricultural mechanization. This is in contrast to the previously generated textured 3D model, which provides a global representation of the relief and surface, but with visible limitations in terms of close-up resolution. The tiled model facilitates detailed exploration without substantial loss of quality or extended loading times - Figure 5.

In the case of the initial textured 3D model, it was determined that the fine surface details, which are imperative for detailed crop analysis, were not adequately rendered. This was attributable to two factors: firstly, the resolution limitations inherent in the generated texture, and secondly, the methodology by which the visual information was applied to the model's surface. Texture has the capacity to "mask" reconstruction imperfections or to homogenise terrain features, thereby rendering it challenging to observe subtle yet significant discrepancies - Figure 6.

The tiled model has been structured into tiles, thereby enabling a smooth and detailed view of the entire studied area, regardless of the zoom level. In the context of our research, this is of crucial importance, as interpreting subtle variations in relief or vegetation structure can substantially contribute to the identification of affected areas, the monitoring of soil moisture, or the planning of agrotechnical work.

To facilitate a more profound comprehension of the subject, the tiled model is an approach that divides the total surface into a number of tiles. Each individual tile is processed and stored with its own geometry and texture data. It is evident that the greater the number of tiles, the smaller the area of each individual tile and the more triangles connecting points it can contain. In addition, a dedicated texture map at a higher resolution for each tile is required. Each tile is expressed in terms of dimensions in pixels; in this context, a tile size of 256 pixels was selected, the smallest possible selectable tile size.

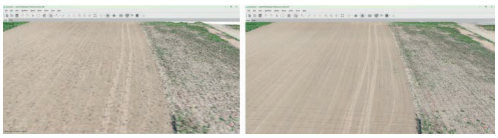


Figure 5. Resolution and detail quality for the textured 3D model at a very high zoom level (left) vs. Resolution and detail quality for the tiled model at the same zoom level (right)

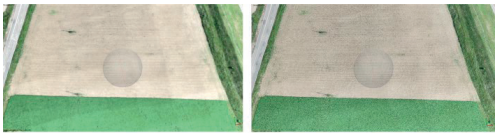


Figure 6. 3D model without texture (left) and with applied texture (right)

Validation and analysis

UAV photogrammetry offers a high-efficiency approach for deriving crop-height metrics, providing accuracy levels appropriate for validating the generated results. These methodologies yield 3D point clouds and Digital Surface Models (DSMs), which, upon

validation consisting of comparing the photogrammetric outputs with ground control points, furnish precise, spatially continuous measurements across entire plots. This approach circumvents the labour-intensive constraints inherent in conventional destructive sampling techniques (Bendig et al., 2014; Tang et al., 2021).
The resulting 3D model and orthophoto provided the spatial data used for subsequent assessment of crop condition patterns, identification of vegetation variability and weed affected zones.

RESULTS AND DISCUSSIONS

Photogrammetric outputs

The quality requirements for point clouds and surface models in agricultural monitoring are driven by the need to accurately measure plant structures, estimate biomass, and navigate machinery (Zhu et al., 2024). The photogrammetric processing produced a dense point cloud and 3D surface models with geometric accuracy suitable for field-scale crop assessment. The surface deviations are ranging from 0 to 9 mm, ensuring that canopy height estimates and spatial comparisons across the study area remained reliable. The final surface model exhibited centimetre level vertical precision, consistent with typical UAV-based agricultural monitoring requirements (Tomaštík et al., 2017; Zhu et al., 2024).
The digital terrain model (DTM) generated from the ground classified points provided a stable reference for isolating plant height. After applying statistical filtering to remove noise and non-ground artefacts, the DTM supported the computation of crop height values across the monitored area, capturing fine scale structural variability within the alfalfa canopy. This enables the identification of zones with reduced growth or irregular development.
Analysis of the dense point cloud and derived canopy height model revealed heterogenous vegetation patterns within the surveyed area.

Crop monitoring performance

The results of the investigation are presented across three key areas of analysis: the spatial distribution of crop height and vigour; the identification of stress zones (water deficit, nutrient deficiency, and lodging); and the temporal changes observed across growth stages.
The identification of issues arising from the analysis:

- In the alfalfa crop, small gaps are visible in several areas of the plot (Figure 7). These gaps regions correspond to areas where plant life has been compromised.

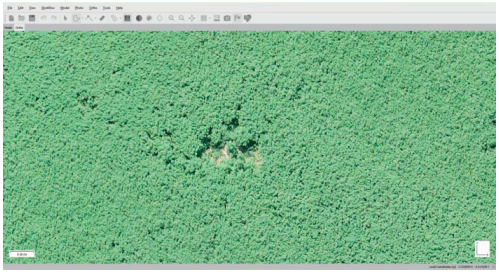


Figure 7. Gap areas in the alfalfa crop

- The second problem observed in the plots of land concerned is the weed infestation on the plot of land where a corn crop was recently sown. As illustrated in Figure 8 left, the areas exhibiting a high degree of weed infestation are delineated from the periphery of the plot towards its interior. The visual interpretation revealed the presence of weed infestation across the majority of the plot's surface, not merely in areas exhibiting a more pronounced green hue - Figure 8 right.

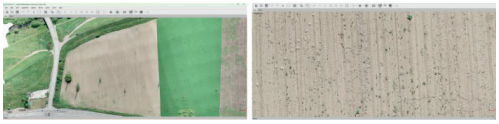


Figure 8. Areas with a high degree of weed infestation vs. weed infestation across the entire plot's surface

Discussions

The results of the study demonstrate that UAV-based photogrammetry provides the level of spatial detail required for parcel-scale crop assessment. The centimetre-level accuracy achieved in the 3D reconstruction enabled the reliable extraction of canopy height patterns and the identification of localised anomalies within the alfalfa field. These capabilities directly support the detection of uneven vegetation growth and weed affected areas observed in the orthophoto and canopy height

model (Amarasingam et al., 2022; Pitton, 2025).

While the general advantages of UAV photogrammetry – high spatial resolution, flexible acquisition timing, and non-destructive monitoring- are well established, the present results confirm their practical relevance for the study area (Amarasingam et al., 2022; Pitton, 2025).

In particular, the ability to resolve fine-scale structural variability, which would not be detectable using satellite imagery, proved essential for interpreting field level conditions.

The findings also highlight the complementary role of UAV data within a broader monitoring framework, where satellite observations can guide the identification of zones of interest, and UAV surveys can provide the detailed structural information needed for targeted agronomic decisions (Guebsi et al., 2024; Pitton, 2025; Voss et al., 2025).

CONCLUSIONS

Recent advances in geospatial technology have led to a significant transformation in how agricultural land is monitored, analysed and managed. This paper puts forward a contemporary approach to using drone-based aerial photogrammetric technologies to monitor crops and agricultural land. This method is recognised for providing accurate, georeferenced data quickly, and it is also transforming the traditional approach to managing agricultural land (Enemark, 2007). The results show that photogrammetric products, including 3D models and orthophotos, allow detailed assessment of crop conditions, supporting the identification of stress factors such as diseases, pests, and water deficits. In addition, the approach proves effective for precise parcel delineation, contributing to land use updates.

The study also confirms the practical value of UAV-based photogrammetric data in agricultural management, including reliable are estimation, productivity assessment, and documentation support for subsidy applications. Furthermore, 3D terrain and surface models enhance the understanding of land characteristics, supporting better land management.

Overall, the purposed approach contributes to improving efficiency, resource optimization, and non-invasive monitoring in agriculture. However, its application remains constrained by factors such as limited flight duration, weather dependence, and the need for technical expertise.

In conclusion, UAV-based photogrammetry represents a reliable and versatile tool for modern agriculture, offering significant benefits for crop monitoring, land management, and decision support.

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