Implementation of a complete process for the collection, processing and use of multi-spectral UAV data for agriculture

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1 INTRODUCTION

Agriculture, a historical cornerstone of the French economy, stands at the dawn of an unprecedented transformation thanks to the emergence of innovative technologies. In this ever-evolving context, the use of UAVs equipped with multispectral cameras has emerged as a major revolution, redefining traditional agricultural practices and offering new perspectives to address contemporary challenges.

However, with growing imperatives such as the need to produce more to meet global food demand while minimizing environmental impact, new approaches are required. UAVs equipped with multispectral cameras are positioned as essential tools in this transition towards more efficient, sustainable, and precise agriculture.

At the heart of this revolution lies the convergence between aeronautics, cutting-edge technology, and agronomy. These UAVs, equipped with sophisticated sensors capturing data at multiple wavelengths, provide an unprecedented view of agricultural lands. Beyond the human eye, this vision allows for a thorough analysis of crops, revealing unsuspected details about plant health, soil composition, and much more.

In this report, we will delve deeply into the impact, applications, and challenges of using multispectral camera UAVs in French agriculture. We will highlight the benefits they offer to farmers, researchers, and decision-makers by providing crucial information for optimized crop management, more efficient use of resources, and informed decision-making.

We will begin with an exploration of the evolution of the French agricultural sector and the contemporary challenges it faces. Subsequently, we will delve into the fundamental principles of multispectral camera UAVs, their unique capabilities, and their revolutionary potential. Through specific case studies in France, we will illustrate the concrete applications of these UAVs in crop monitoring, early disease detection, and precise land management.

Finally, we will address tangible benefits and current challenges while exploring the future prospects of this technology, envisioning a more resilient, sustainable, and efficient French agriculture.

2 AGRICULTURE AND TECHNOLOGY

2.1 Evolution of agriculture in France

Over the past few decades, French agriculture has undergone a major evolution. Once characterized by small family farms and a diversity of regional crops, it has gradually shifted towards a more specialized, intensive, and technologically advanced agriculture. This transition has been driven by the need to meet growing food demand and remain competitive in global markets.

2.2 The role of new technologies in the agricultural sector

New technologies have played a crucial role in this evolution. The introduction of modern agricultural machinery, controlled irrigation, genetically modified seeds, and more efficient pesticides has significantly increased productivity and yields. Geographic Information Systems (GIS) have allowed better land management, while satellite remote sensing has provided valuable tools for monitoring crops on a large scale.

2.3 Current needs and challenges facing French agriculture

However, despite these advancements, French agriculture is facing a series of crucial challenges in the 21st century. Environmental sustainability has become a major concern, with pressures to reduce the use of chemicals, limit soil erosion, and minimize the carbon footprint of agriculture. Biodiversity preservation and responsible water management are also central concerns.

Simultaneously, French agriculture is grappling with social issues such as maintaining rural employment, preserving the traditional agricultural fabric, and ensuring equitable income distribution in the sector. Additionally, resilience to climate change, with increasingly frequent extreme weather events, poses a major challenge to ensuring stable harvests and food security.

To address these challenges, French agriculture is moving towards a smarter and more targeted use of new technologies. The rise of precision agriculture, combining advanced sensors, UAVs, artificial intelligence, and data analysis, aims to optimize agricultural practices by minimizing inputs and maximizing yields. The goal is to shift from a uniform approach to a more individualized management of plots, tailored to the specific needs of each crop.

French agriculture, witness to a long history of innovations and transformations, stands at a crucial turning point. Contemporary challenges demand an innovative and sustainable approach that seamlessly integrates technological advancements while respecting environmental and social imperatives. The judicious and ethical adoption of new technologies is a promising path towards a more efficient, resilient, and environmentally friendly French agriculture.

3 INTRODUCTION TO MULTI-SPECTRAL CAMERA UAVS

3.1 What is a multispectral camera UAV?

UAVs equipped with multispectral cameras represent the cutting edge of agricultural observation, combining aeronautical engineering and advanced technology to offer a unique perspective on crops. These sophisticated devices incorporate cameras capable of capturing data at different wavelengths, transcending the visible light spectrum and revealing crucial information for plant health.

A multispectral camera UAV is an unmanned flying device equipped with sensors capable of collecting data in multiple spectral bands. These multispectral cameras go beyond simple capture of visible images to the human eye, recording data in near-infrared, thermal spectrum, and other specific wavelengths.

3.2 Operation and technical specifications

The heart of this technology lies in multispectral sensors, which record the light reflected by crops in different wavelengths. Each captured wavelength corresponds to a specific characteristic of plants, such as chlorophyll, leaf health, or water stress. This data is then processed to provide detailed information about the vegetation's.

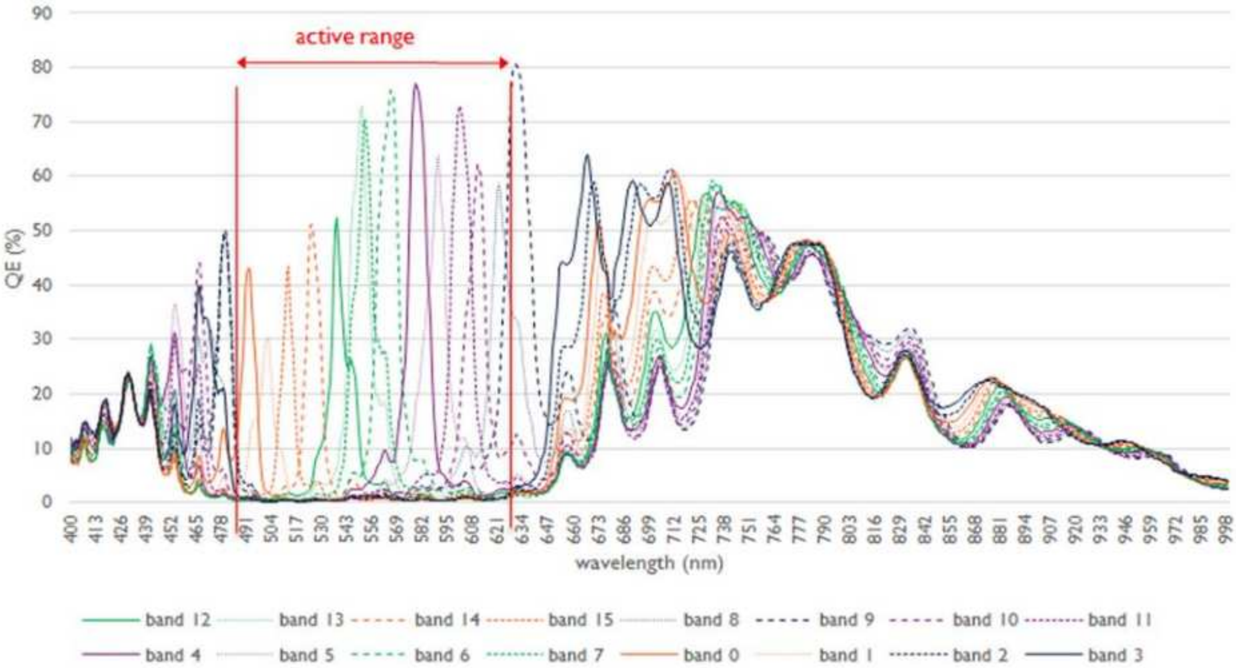

Figure 1 - spectrals bands

Multispectral camera UAVs incorporate various technical features to optimize their performance in the agricultural context. Among these key features are:

• Multispectral Sensors: These sensors record data in different spectral bands, allowing for a thorough analysis of crop health.

• GPS Systems and Autonomy: UAVs are often equipped with advanced GPS systems for precise flights and detailed mapping. Their autonomy may vary, but current models offer extended flight times to cover vast areas.

• Stabilization and Precision: UAVs integrate advanced stabilization mechanisms for precise and stable footage, even in changing weather conditions.

• Real-time Data Transfer: Some models allow for real-time transfer of collected data, providing farmers with instantaneous information for quick decision-making.

3.3 Advantages over other monitoring methods

Compared with satellites, including new nanosatellite technologies with high-quality sensors, high spatial and temporal resolution, and storage of historical data in catalogues, UAVs are increasingly offering advantages. This is due to their ease of use with different types of sensors, high radiometric, spectral, geometric and spatial resolution, and faster configuration of general parameters (Maes, W. H., et al., 2019).

	Spatial Resolution	Field of View	Usability	Payload Mass	Cost for Data Acquisition
UAV	0.5–10 cm	50–500 m	very good/easy	can be limited	very low
Helicopter	5–50 cm	0.2–2 km	pilot mandatory	almost unlimited	medium
Airborne	0.1–2 m	0.5–5 km	pilot mandatory	unlimited	high
Satellite	1–25 m	10–50 km	-	-	very high, particularly for high-res stereo imagery

Figure 2 - Comparison of UAV with Other Data Sensors (Candiago, S., et al., 2015).

At the same time, precision agriculture is expanding and gaining more space. It is defined as a crop management strategy that utilizes new information technologies to reduce production costs, minimize environmental impact, and increase and enhance agricultural production (Sishodia, R. P., et al., 2020).

Simultaneously, the central, western, and northwestern parts of the Occitanie region are experiencing promising growth in the agricultural market. Due to the potential for conducting studies aimed at improving yields in agriculture, a strong demand has been projected for multispectral sensors.

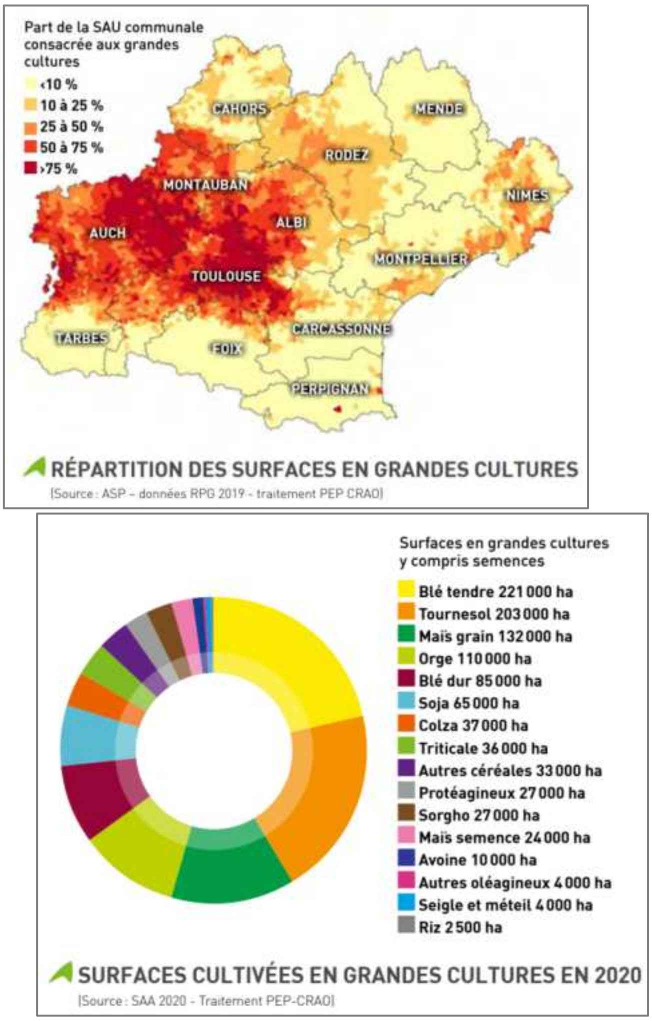

Figure 3 - SAU Map of the Occitanie Region and Proportion Map of Major Crops in Occitanie

4 EXAMPLES OF USE IN FRANCE

4.1 Case studies on French farms

The materials and working equipment primarily included: a computer for research, writing, data processing, and studies; a DJI RC PRO remote control for UAV flight planning; a MAVIC M3M PRO RTK UAV for field data collection; SD cards of various sizes and brands for data storage during data collection; and a DJI D-RTK PRO 2 GNSS base station for georeferencing during UAV flights.

Initially, the DJI Pilot application was used to create flight plans, as previously done by the company for this task. However, due to the difficulty in creating polygons for areas of interest directly on the remote control, I opted to form the polygons using Google Earth. Subsequently, I imported the vector files and formed the flight plans using the flight parameters studied in the first phase.

Figure 4 - Flight Planning Diagram

UAV flights and data collection dates were scheduled based on a developed calendar (Figure 3) to align with the planting, growth, and harvest dates and availabilities during the internship period.
For UAV flights, three main pieces of equipment were consistently used: the UAV (DJI Mavic M3M RTK), the remote control (DJI RC Pro), and the GNSS geolocation station (DJI D-RTK 2).

Figure 5 - Equipment Used for Flights.

4.2 Data processing

For the pre-processing and processing steps of multispectral flight data, it was decided to use Agisoft Metashape software, as it was already widely utilized by the company in projects involving images from other types of sensors.
There was also consideration and an attempt to carry out processing using Pix4D software, but the limited interest in this solution led to the cancellation of that option.
Due to the large volume and heaviness of the data (matrix data times 7 bands), it took days to generate the products from the raw data processing. A solution to reduce this timeframe was to test and understand, based on the study's requirements, what resolution would be necessary for the analyses. Thus, processing parameters were adjusted, and the images, initially ranging from millimeter to 1 cm scale resolution, were standardized to a 5 cm spatial resolution.
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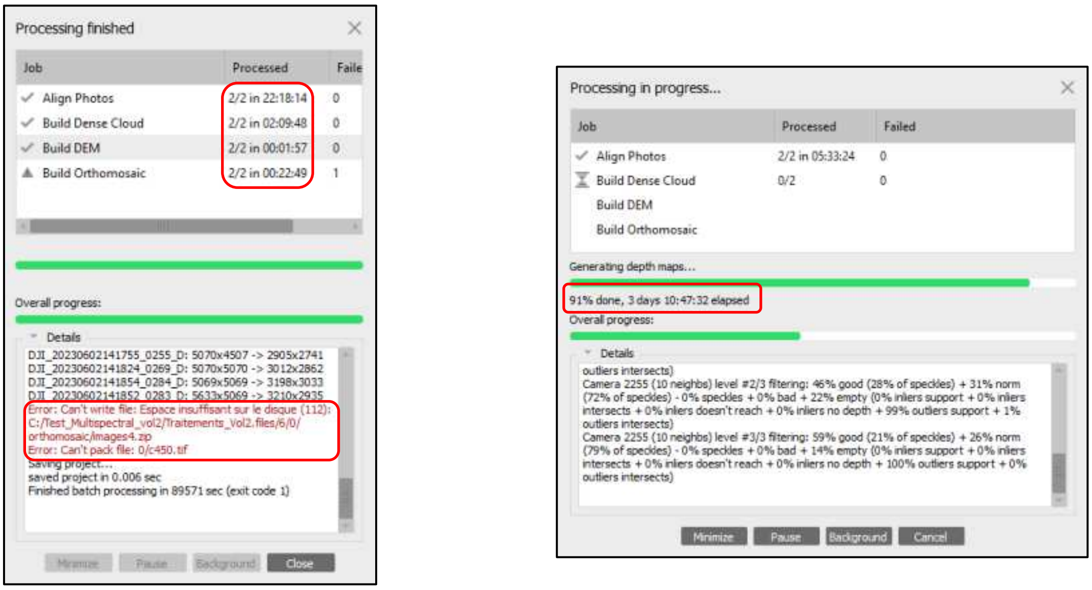


Figure 6 - Processing times.

Between the first and second flights, I noticed a potential problem with the edges of the images, where the values seemed distorted in relation to the more central parts.

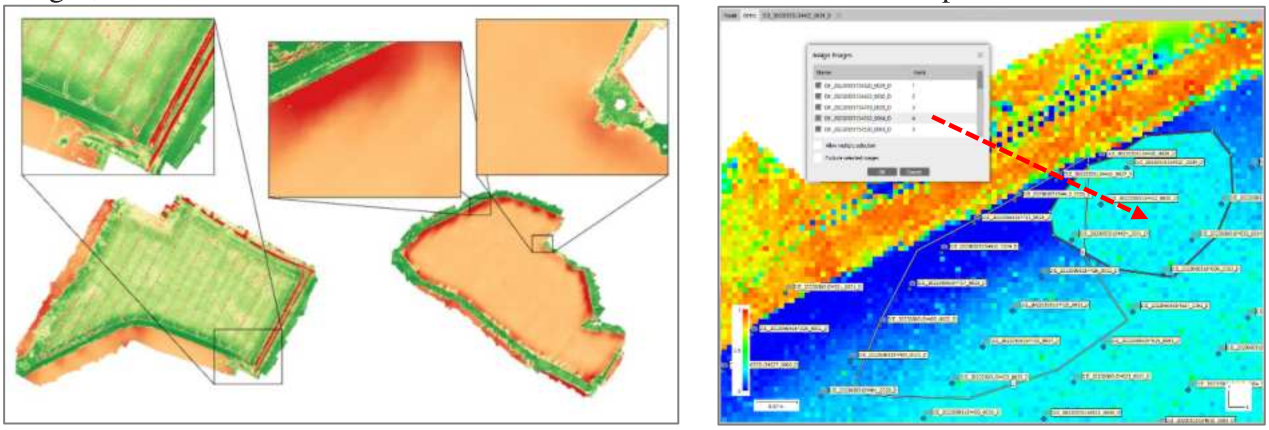


Figure 7 - Edge problems.

Given camera parameters such as focal length and geometry, if not properly defined, they can cause distortions in images, disrupting the accuracy of ortho-images. Photogrammetry, based on stereoscopic triangulation, leverages these images to generate 3D models by correcting distortions, ensuring reliable results.

In seeking to understand the reason for the border issue, I realized that it was more common when the images were not taken in nadir. I then considered that the formation of ortho-images used compositions with parts of images that may exhibit border distortions. To remedy this, I applied a 10-meter buffer during subsequent flights.

Among the preprocessing steps, the software automatically performs reflection calibration, image alignment, and tie point creation. As for the processing steps, the generation of dense clouds, digital elevation model (DEM), and orthomosaic is also done automatically.

From there, the tools and means to process the generated data were all chosen by myself, based on research and advice from individuals outside the company but related to geomatics.

The most important data for this study were the orthomosaic, dense cloud, and digital elevation model (DEM). From these three products, it was possible to produce other elements that enabled analyses. For example, from the dense cloud, classified between ground and vegetation by Global Mapper software, the digital terrain model (DTM) and digital surface model (DSM) were generated; from the orthomosaics, vegetation indices were created; and from the elevation models, topographic analyses were conducted.

The sensor generates orthographic images comprising seven bands:

- Band 1: Red (RGB Sensor);
- Band 2: Green (RGB Sensor);
- Band 3: Blue (RGB Sensor);
- Band 4: Green (Multispectral Sensor);

- Band 5: Red (Multispectral Sensor);
- Band 6: Red Edge (Multispectral Sensor);
- Band 7: Near Infrared (Multispectral Sensor).

The acquisition and regulation of the correct geographic coordinate system, as well as the delineation of the actual area of interest and removal of "NO DATA" values, were performed using QGIS software. Additionally, the elements of orthomosaic, DTM, and DSM were also imported and processed in the same software.

Analyses were conducted using the three data collection dates with the aim of achieving a temporal analysis of the crops.

SAGA GIS software was also utilized for the plant counting study. By calculating the difference between DSM and DTM, applying a Gaussian filter, and undergoing watershed processing, the number of plant individuals was assessed.

The plant counting study encountered certain challenges related to plant density, height, the accuracy of a good DTM (Digital Terrain Model) generated, growth stage, and the presence of weeds. Increased difficulties were observed in cereal and oilseed crops, while tests on fruit trees were much less frequent.

5 APPLICATIONS FOR MULTISPECTRAL UAVS IN AGRICULTURE

5.1 Plant counts

As mentioned earlier, plant counting involves calculating the difference between DSM and DTM, which is then processed using a Gaussian filter and the watershed method. Although another method of automatic segmentation could have been used, it was chosen to follow the watershed method due to its simplicity and the availability of a large number of resources on the applied method.

5.2 Plant height

Following the classification of the dense cloud, a subtraction operation was carried out between the DSM (Digital Surface Model) and DTM (Digital Terrain Model) products. This allowed obtaining the digital height model (DHM), representing the vegetation height relative to the ground. By regularly measuring plant height, it was possible to adjust agricultural practices such as irrigation and fertilization to optimize crop yield and quality.

This study method was chosen to provide a general idea of the homogeneity of crop growth and enable comparisons with other dates.

5.3 Soil classification

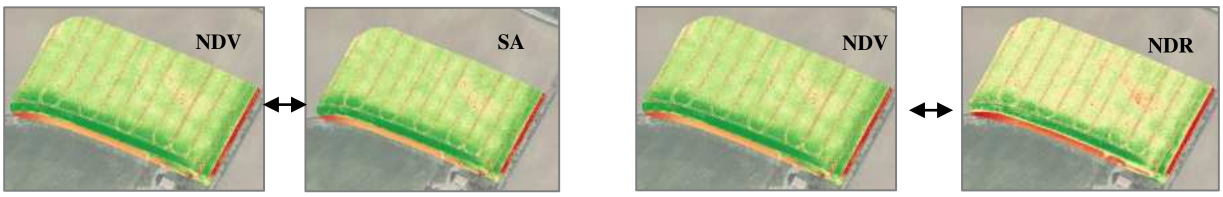
For this study, a database of NDVI and samples of different soils is used. This allows differentiating and highlighting various types of clusters, such as bare soil, actively growing vegetation, dried vegetation, and others. This practice can assist in fertilization planning and adopting agricultural practices suitable for each soil type. It is also valuable for land use planning and natural resource management. This method was chosen to demonstrate the formation of these clusters on a scale of the cultivation area.

5.4 Vegetation zone

Designed to generalize and provide an idea of the density and areas of missing vegetation. After the classification and identification of vegetation classes, a grid is created based on the working scale. This grid measures the vegetation cover percentage for each square, offering an overview of the vegetation in the field. The decision to apply this study was motivated by the desire to obtain a real-time view of the current state of the crop in terms of vegetation.

5.5 Vegetation vigour and stress analysis by vegetation index

To select the representation and interpretation of vegetation analysis, three main vegetation indices were initially considered: Normalized Difference Vegetation Index (NDVI), Soil-Adjusted Vegetation Index (SAVI), and Normalized Difference Red Edge Index (NDRE). However, a correlation analysis using linear regression revealed significant correlations between these indices. Therefore, it was decided to use the classic and widely recognized NDVI for this type of analysis, based on the red and near-infrared bands, to assess crop health.



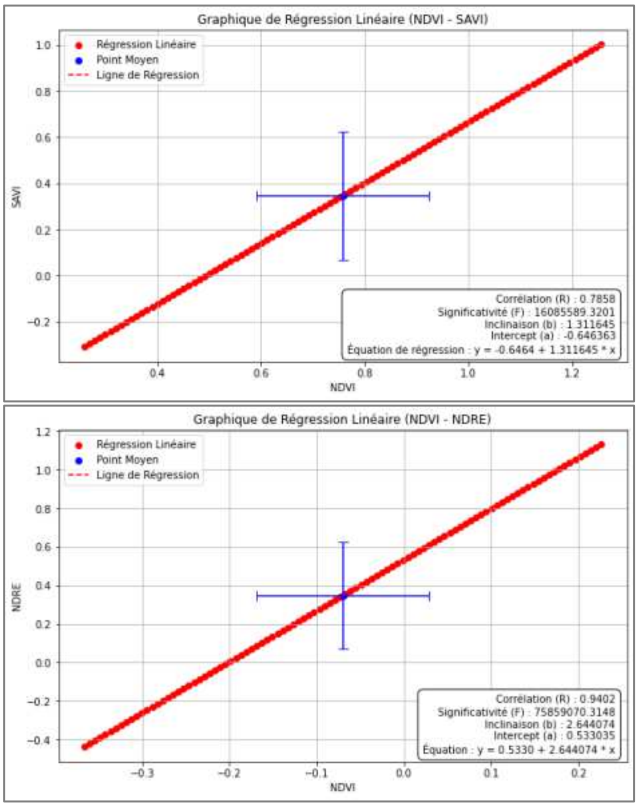


Figure 8 - Correlation analysis.

F (Model Significance): The F-test evaluates whether the independent variables in the regression model have a significant overall impact on the dependent variable. A high value indicates that the model significantly explains the observed variations.

R (Correlation): The correlation coefficient R measures the strength and direction of the linear relationship between variables. Closer to 1, it indicates a close correlation between variables.

b (Slope): The coefficient b represents the slope of the regression line. A positive value means that an increase in the independent variable leads to an increase in the dependent variable (and vice versa).

a (Intercept): The coefficient a is the intercept of the regression line, indicating the estimated value of the dependent variable when the independent variable is zero. This gives the starting point of the linear relationship.

Therefore, it would be most appropriate to use the NDVI associated with a standardized value palette. This method provides crucial information for optimal crop management, irrigation, fertilization, and decisions related to yield and crop health.

Another method of analyzing vegetation vigor is the calculation of vegetative area, measuring the surface covered by vegetation using a mask to differentiate it from bare soil. This measurement allows quantifying vegetation cover, monitoring crop growth, and detecting areas under stress. This information is essential for optimizing crop management, improving yields, and promoting sustainable agriculture.

The choice of the NDVI index was motivated by its simplicity and familiarity, even for those outside the field of geomatics. Moreover, this index allows deducing the possibility of stress in an area with a low index value.

5.6 Sun exposure

In order to explore the multiple possible reasons for the situations encountered in crop analyses and increase interpretation possibilities, the implementation of field studies has been considered. The study of solar exposure by terrain orientation could be useful, as vegetative growth is directly linked to the solar energy source. This study relies on the terrain model to determine its orientation and receive the greatest solar exposure.

5.7 Slop

To understand the slope of the terrain, slope calculations are performed using the terrain model data. This can be a valuable resource to optimize resource use by adapting agricultural practices based on the topography. It was chosen to include this type of study in addition to understanding the terrain features.

5.8 Contour

In order to assess the overall terrain relief, contour line studies are conducted. Terrain model data is used to create lines at regular intervals based on the working scale. This helps to better understand the distribution of surface water, plan irrigation, and design appropriate drainage systems. The decision to include this study with others is also motivated by the desire to gain a comprehensive understanding of the terrain.

5.9 Flow direction

The flow direction refers to the path that water takes as it moves across terrain. It is typically calculated from digital terrain models. In agriculture, this information is crucial for water management, especially in designing irrigation and drainage systems. It aids in planning irrigation routes, identifying areas at risk of water accumulation, and preventing issues related to water flow. The decision to implement this type of study is primarily motivated by the desire to enhance the understanding of the interaction between rainfall and the terrain.

6 ADVANTAGES, LIMITATIONS AND PROSPECTS

6.1 Advantages of multispectral UAVs for agriculture in France

Precise Crop Monitoring: Multispectral UAVs enable regular and detailed monitoring of crops over large areas, providing accurate data on plant health. This allows for early detection of diseases, nutrient deficiencies, or pest infestations.

Optimization of Irrigation and Inputs: By identifying specific areas requiring different treatments or irrigation, these UAVs enable more precise resource management, thereby reducing the use of fertilizers, pesticides, and water.

Improved Yields: The collected data helps farmers make more informed decisions, often resulting in increased yields and maximized agricultural production.

Operational Cost Reduction: More targeted input management leads to a reduction in operational costs for farmers, while minimizing the environmental impact associated with excessive chemical use.

6.2 Limitations and challenges faced

Complexity of Data Processing: The collection of massive data by UAVs requires specialized skills for processing, analysing, and interpreting them. This can be a challenge for many farmers who may not have the necessary expertise.

High Initial Cost: The acquisition and maintenance of UAVs with multispectral cameras can entail a high initial investment, potentially limiting accessibility for some farmers, especially those with small-scale operations.

Regulations and Privacy: Regulations related to UAV use, as well as concerns about the privacy of collected data, are aspects to consider and may pose challenges in adopting this technology.

6.3 Future prospects for this technology

Technological Advancements: Progress in data processing technologies and sensor miniaturization could make multispectral UAVs more accessible and user-friendly for a broader range of farmers.

Training and Education: Training and education programs aimed at familiarizing farmers with UAV use and developing their data analysis skills could contribute to a more widespread adoption of this technology.

Development of Integrated Solutions: Integrating multispectral UAVs with other agricultural technologies such as artificial intelligence and crop management systems could open new possibilities for precision farming.

Despite some current limitations, the use of UAVs equipped with multispectral cameras offers significant benefits for agriculture, improving land management, productivity, and sustainability. The future prospects for this technology are promising, requiring efforts to overcome current challenges and ensure wider and more effective adoption in the agricultural sector.

7 CONCLUSION: COMPLEMENTARITY BETWEEN MULTISPECTRAL SATELLITE AND UAV IMAGERY IN AGRICULTURE

Advantages of Multispectral Satellite Images

Satellites provide a global view of farmlands, enabling large-scale monitoring. Their regular capture frequency provides continuous and historical data on crops.
Satellite sensors have a range of wavelengths, allowing for detailed analysis of crops. Their temporal resolution provides crucial seasonal data.
Satellite images are generally less expensive to acquire and accessible to all, offering a cost-effective solution for large-scale monitoring.

Advantages of Multispectral UAV Images
UAVs capture images at high spatial resolution, providing precise details of specific areas suitable for accurate crop management.
UAVs can be deployed in a targeted manner, offering flexibility for capturing images at specific times and in areas defined by farmers' needs.
UAVs allow customization of image capture missions, providing precision tailored to the specific needs of farmers for accurate crop management.

Complementarity and Synergies
Satellite images provide a global view, while UAV images offer detailed resolution at smaller scales. By combining this data, a comprehensive analysis of crops can be conducted.
UAV images can be used to validate or verify details observed in satellite images, thereby enhancing the reliability of collected information.

The combination of these images allows agile crop management, offering a global view while enabling targeted interventions where specific issues are identified.

The complementarity between multispectral satellite and UAV images holds immense potential for agriculture. Their combined use provides a holistic view of farmlands, combining the global perspective of satellites with the detailed precision of UAVs. This synergy allows for precise, efficient, and sustainable crop management, paving the way for smarter and more efficient agriculture.

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BIOGRAPHICAL NOTES

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