DIGITALIZATION OF AGRICULTURAL LAND THROUGH UAV–GIS TECHNOLOGIES IN THE CONTEXT OF AGRICULTURE 5.0

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Abstract

In the context of global challenges related to agricultural sustainability and resource-use efficiency, 3D mapping technologies based on unmanned aerial vehicles (UAVs) have become essential tools for planning precision agricultural operations. This article examines the potential of UAV platforms equipped with photogrammetric and LiDAR sensors to generate Digital Terrain Models (DTM) and Digital Elevation Models (DEM), which have direct applications in optimizing irrigation, drainage, land-leveling, and variable-rate seeding systems. The study highlights the role of integrating these 3D models into Geographic Information Systems (GIS), enabling advanced spatial analysis and data-driven decision-making. Through concrete examples of UAV–GIS workflows, the advantages of interoperability between digital platforms and modern agricultural machinery are emphasized.

Furthermore, the article positions this technology within the transition from Agriculture 4.0—focused on automation and data acquisition—to Agriculture 5.0, an emerging paradigm that leverages artificial intelligence, human–machine collaboration, and ecological sustainability. In this context, 3D mapping contributes to the development of intelligent, resilient, and forward-looking agriculture, where decisions are guided by high-resolution geospatial data. Finally, the paper provides a critical assessment of the benefits, limitations, and challenges associated with the large-scale adoption of these technologies, proposing future research directions and implementation models tailored to both Romanian and international agricultural contexts.

Key words: UAV, GIS, Precision Agriculture, Agriculture 5.0

INTRODUCTION

Contemporary agriculture is at a critical juncture, confronted with increasing productivity demands, environmental constraints, and climatic instability. In this context, precision agriculture (PA) has emerged as an integrated solution grounded in the collection and analysis of data to tailor agricultural inputs—seeds, water, fertilizers, and pesticides—to the spatial and temporal variability of the land. The principle of “the right resources, in the right amount, at the right place and time” marks the transition from traditional agriculture to a digitalized and differentiated production system (Călina J. et al., 2022).

The origins of PA date back to the 1980s, with the introduction of GPS in agricultural operations, while subsequent advancements in sensing technologies, communications, IoT, big data, and artificial intelligence have further consolidated this concept. Today, PA constitutes a strategic direction supported internationally and is applicable to both large-scale farms and small family holdings (Călina J. et al., 2025). By enabling precise input application, it reduces nutrient losses, greenhouse gas emissions, and waste, while simultaneously increasing economic efficiency.

The success of PA depends heavily on the quality of spatial and agronomic data, and remote sensing and mapping technologies—particularly unmanned aerial vehicles (UAVs)—play a pivotal role in this respect. UAVs have revolutionized agricultural data collection by providing high-resolution imagery at low costs and with greater operational flexibility than traditional methods (Bwambale et al., 2025). Due to their low-altitude flights, drones can capture details at centimeter-level resolution, identifying areas affected by water stress, disease, or nutrient deficiencies and enabling frequent, near-real-time monitoring.

Equipped with multiple sensors—RGB, multispectral, hyperspectral, thermal, or LiDAR—UAVs generate complex datasets for crop health assessment, early detection of anomalies, and the creation of 3D terrain models (Vangu et al., 2022). The information collected is integrated into GIS platforms and decision-support systems, contributing to thematic mapping, differentiated management zones, and predictive modeling.

Drones can operate effectively even under challenging conditions, enabling rapid monitoring without disrupting agricultural activities. However, widespread adoption is hindered by regulatory barriers, costs, and the need for specialized technical skills. Standardized integration with GIS systems and collaboration among developers, researchers, and farmers are essential for fully harnessing the potential of UAV-derived data (Călina J. et al, 2021).

UAVs represent a key technology for the digitalization and modernization of agriculture, supporting the transition toward Agriculture 5.0—an emerging model founded on artificial intelligence, automation, and sustainability. Through precise spatial data, drones optimize resource use and minimize environmental impact.

Three-dimensional mapping plays a central role in this transformation. Digital Terrain Models generated via UAVs provide critical information for land leveling, drainage management, and irrigation design. These models enable precise planning of agricultural operations, preventing erosion and water stagnation while reducing costs and environmental risks. They also support the analysis of natural water flows, the identification of risk-prone areas, and the development of efficient drainage and irrigation systems.

3D mapping further facilitates the estimation of soil volumes, slope analysis, agricultural infrastructure planning, and the monitoring of topographic changes caused by natural phenomena or anthropogenic activities. Integrating these data into a GIS allows correlations between topography and agronomic parameters (soil types, moisture levels, crops), ultimately resulting in more informed and customized decisions (Călina A. et al, 2019).

Effective implementation of 3D mapping requires high-performance equipment, interdisciplinary expertise, and substantial initial investments; however, ongoing technological advancements are making this solution increasingly accessible, transforming it into an essential tool for modern and sustainable agriculture.

As Agriculture 4.0—rooted in digitalization, automation, and large-scale data collection via IoT, GPS, and UAVs—evolves, a new stage is emerging: Agriculture 5.0, characterized by human–machine collaboration and AI-driven decision-making. This new paradigm does not replace the farmer; instead, it enhances their role through intelligent tools that enable rapid and sustainable decisions.

Agriculture 5.0 promotes sustainability, resource optimization, and ecosystem protection, relying on autonomous systems and predictive data analytics. In this context, the digitalization of agricultural land through 3D mapping with UAVs and the integration of derived datasets into GIS become fundamental components (Călina J. et al, 2021).

The aim of this article is to highlight the contribution of UAV technologies to the development of intelligent and sustainable agriculture. By providing detailed digital models of the terrain, these technologies optimize agricultural operations, increase productivity, and reduce environmental impacts. The article presents UAV-based 3D mapping methods, GIS data integration techniques, and their role in the transition toward Agriculture 5.0—a system grounded in artificial intelligence, human–machine collaboration, and sustainability, which is redefining the future of agriculture.

THEORETICAL FOUNDATIONS

Agriculture 4.0 vs. Agriculture 5.0

Over the past decades, agriculture has undergone profound transformations driven by digitalization and automation. The concept of Agriculture 4.0 designates this stage, characterized by the use of IoT, sensors, drones, GPS, automation, and big data analytics. The primary objective has been to increase efficiency, reduce costs, and improve productivity. These technologies have enabled real-time data collection on soil, crops, and climate, providing farmers with advanced monitoring and decision-support tools. Figure 1 shows the main differences between Agriculture 4.0 and Agriculture 5.0.

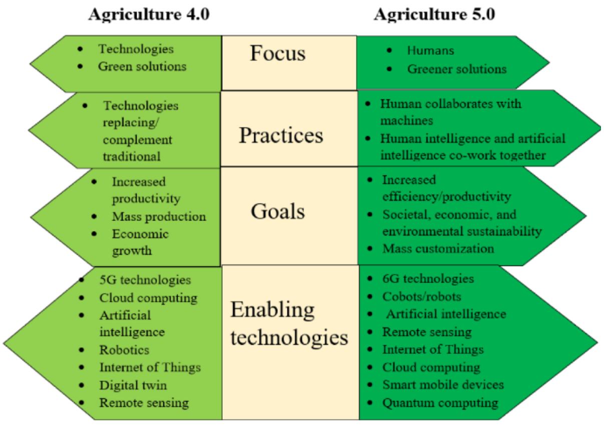

Figure 1. Main differences between Agriculture 4.0 and Agriculture 5.0 (Bissadu et al., 2025)

However, growing concerns about environmental impact and sustainability have led to the emergence of Agriculture 5.0, an evolutionary stage that builds upon the principles of digitalization while emphasizing adaptability, resilience, and human–machine collaboration. (Uztürk et al., 2024) While Agriculture 4.0 focuses on automation and control, Agriculture 5.0 integrates artificial intelligence, machine learning, edge computing, and collaborative robotics to develop autonomous and environmentally responsible agricultural systems (Mandal et al., 2024).

In this new paradigm, technology becomes an active partner in decision-making, capable of interpreting complex datasets and generating predictive recommendations regarding soil health, resource requirements, or climate-related risks. Edge computing ensures local processing of data, reducing dependence on cloud infrastructure, while cobotics promotes safe interaction between humans and machines—robots handling repetitive tasks so that farmers can concentrate on strategic decisions.

Thus, Agriculture 5.0 establishes a balance between efficiency and sustainability, prioritizing environmental protection, adaptability, and human well-being. It represents a necessary paradigm shift in response to current challenges related to food security, climate change, and the conservation of natural resources.

3D Mapping in Agriculture

Three-dimensional land mapping (figure 2) is an essential tool of modern agriculture, providing a precise understanding of topography that directly influences crop management. It relies on two complementary technologies—photogrammetry and LiDAR—used to generate high-accuracy Digital Terrain Models (DTM) and Digital Surface Models (DSM).

Photogrammetry uses overlapping aerial images that are algorithmically processed to reconstruct the 3D shape of the terrain. It is an accessible and efficient method that provides detailed information about soil texture and color, making it valuable for land assessment and crop monitoring. In contrast, LiDAR emits laser pulses that measure the distance to the ground, delivering highly accurate data even in areas with dense vegetation. This capability enables the detection of micro-relief features and fine topographic details (Pop et al., 2024).


Figure 2. Land mapping by drone (https://www.cohga.com/diy-drone-mapping-workshop-for-agriculture)

The resulting models (DTM and DSM) provide essential support for agricultural activities such as land leveling—preventing water stagnation and erosion—and drainage system design through the identification of natural water flow paths. In irrigation management, 3D mapping optimizes uniform water distribution, contributing to resource savings and soil health preservation.

Additionally, these models are used for monitoring erosion processes and terrain changes caused by natural phenomena or human activities, allowing timely corrective interventions.

Therefore, 3D mapping based on photogrammetry and LiDAR offers an integrated perspective on agricultural land, supporting precise and efficient decision-making. Through its integration into GIS systems, this technology directly contributes to optimizing production, reducing operational costs, and strengthening sustainable and environmentally responsible agriculture.

METHODOLOGY, EQUIPMENT, MAPPING AND PROCESSING TECHNIQUES, AND INTEGRATION WITH GIS SOLUTIONS

Unmanned Aerial Vehicles (UAVs) and Associated Equipment

Drones have become indispensable tools in precision agriculture, and selecting appropriate equipment is crucial for obtaining accurate data. Depending on purpose and terrain conditions, two main categories are commonly used: *multirotor and fixed-wing UAVs* (figure 3).

Multirotor drones are valued for their maneuverability and ability to hover, making them ideal for confined areas, orchards, or greenhouses. Their flight autonomy is relatively limited (15–40 minutes), covering smaller areas but providing highly detailed imagery. *Fixed-wing UAVs*, by contrast, are suited for large agricultural areas due to their extended autonomy (over one hour), although they require larger takeoff and landing spaces and cannot hover (Vangu et al., 2022).

The sensors mounted on UAVs directly influence data quality. RGB sensors capture color images suitable for general mapping and orthomosaic generation. Multispectral sensors collect information in specific spectral bands (near-infrared, red, green), enabling vegetation indices (e.g., NDVI) used for assessing crop health, water stress, and disease presence. Thermal sensors measure soil and plant temperature, supporting irrigation optimization.

Figure 3. UAV-type equipment that can be used in agriculture (Shamshiri et al., 2018)

LiDAR, although more costly, provides high-precision 3D models capable of capturing micro-relief details and vegetation structure.
The selection of UAV equipment must be adapted to the specific operational needs of each farm, as proper combinations of drones and sensors enable the acquisition of precise data for 3D mapping and informed agricultural decision-making.

3D Mapping and Processing Techniques

Three-dimensional mapping of agricultural land using UAVs involves several stages: aerial image acquisition, data processing, and generation of digital products (DTM, DSM, orthomosaic). Figure 4 shows a processing workflow specific to drone photogrammetry.

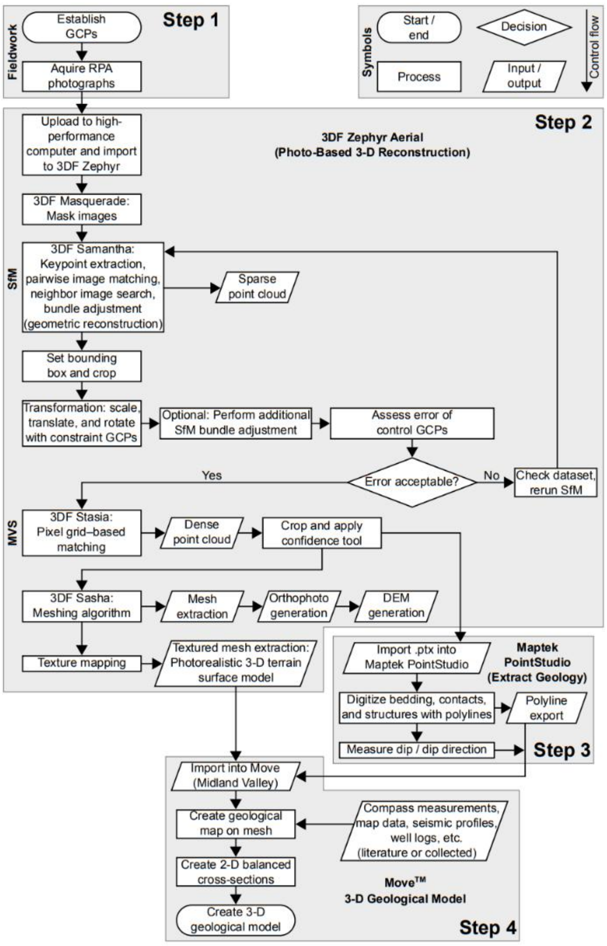

Figure 4. Workflow for photogrammetric processing (Hansman et al., 2019)

Flight planning is based on field size, altitude, and weather conditions. Image overlap — at least 75% frontal and 60% lateral — is critical for accurate 3D reconstruction. UAVs equipped with RGB or multispectral sensors capture hundreds of images, which are processed using specialized software (Pix4D, Agisoft Metashape, DroneDeploy) that employ photogrammetry algorithms and Structure from Motion (SfM) to generate point clouds. From these point clouds, Digital Terrain Models (DTM) — representing the bare-earth surface — and Digital Surface Models (DSM) — including vegetation and objects — are produced. For enhanced accuracy, Ground Control Points (GCPs) measured with high-precision GPS equipment are typically employed (Pop et al., 2024).
An essential output is the orthomosaic, a geometrically corrected image with uniform scale, ideal for thematic mapping. The resulting digital models are then imported into GIS platforms for topographic or hydrological analyses, as well as for identifying erosion-prone or water-accumulation areas.

Integrating UAV Data with GIS Solutions

Integrating UAV-derived data into Geographic Information Systems (GIS) maximizes their value, transforming 3D models and orthomosaics into operational analytical tools. Platforms such as QGIS, ArcGIS, or GRASS GIS allow the import of UAV data (GeoTIFF, LAS, shapefile) and overlay with additional datasets — soil maps, climate data, infrastructure — offering an integrated view of agricultural terrain.
GIS enables spatial analyses (contours, slope, aspect, erosion-risk areas) and the implementation of variable-rate zoning, where the land is divided into homogeneous zones that receive differentiated treatments (fertilization, irrigation). This approach optimizes resource use and reduces environmental impacts (Călina J. et al., 2019).
Hydrological models derived from GIS can simulate water flow, identifying accumulation and runoff areas, thereby

supporting drainage design and irrigation management. Linking GIS with IoT sensors and weather stations allows real-time data updates, facilitating rapid and adaptive decision-making.

The UAV–GIS integration also supports interactive visualizations and dynamic reports, useful for collaboration among farmers, consultants, and policy-makers. Moreover, combining UAV data with artificial intelligence (AI) and machine learning enables automated data analysis and predictive modeling related to crop health or disease emergence (Canicattì et al., 2024).

Key challenges include the need for technical expertise, high-performance IT infrastructure, and data security. Nevertheless, the UAV–GIS synergy constitutes a central pillar of Agriculture 5.0, supporting a sustainable, efficient, and resilient agricultural sector.

PRACTICAL APPLICATIONS IN AGRICULTURAL OPERATIONS

Optimization of Irrigation and Drainage Systems

One of the main applications of UAV technologies combined with 3D mapping and GIS in agriculture is the optimization of irrigation and drainage systems—critical components for ensuring healthy and uniform crop development. Efficient water management directly affects yield, soil quality, and the sustainability of the entire agricultural ecosystem. UAVs enable rapid acquisition of detailed topographic data, generating accurate 3D digital models that capture every elevation change, depression, and terrain feature. These models are essential for simulating water flow, providing precise insights into how water accumulates, infiltrates, and drains across the field.

Using GIS software, the digital models allow the simulation of various hydrological scenarios. Specialists can identify areas vulnerable to water stagnation or erosion and optimize the placement of ditches, channels, and other drainage elements to ensure consistent water flow and prevent crop damage or loss. In fields with variable slopes, water naturally pools in depressions, causing overwatering and root development issues. 3D models help detect these zones and enable the adjustment of drainage systems to avoid such problems.

Additionally, the digital models allow precise planning of irrigation networks. Areas with water deficits or crops with specific water requirements can receive controlled, uniform distribution, thereby conserving resources and reducing environmental impact. For instance, elevated or porous soil zones may require increased water flow, while natural depressions may be irrigated more moderately. Simulations also enable testing potential modifications or improvements to irrigation and drainage systems without physically intervening on the land, thus reducing costs and risks associated with fieldwork.

Integrating GIS with soil moisture sensors and other IoT devices facilitates real-time monitoring of system efficiency and immediate adjustment of irrigation strategies. Farmers can thus make decisions based on actual field conditions, supporting flexible and sustainable resource management.

These technologies enhance crop productivity, reduce water losses, and protect the soil from erosion, aligning with the principles of Agriculture 5.0, which promotes sustainability and intelligent resource use.

Planning Land-Leveling Operations

Land leveling is a crucial step in preparing agricultural surfaces, as it directly influences the efficiency of mechanized operations, crop quality, and water resource management. UAV-based 3D mapping offers a detailed depiction of the field’s actual configuration, highlighting uneven areas, water accumulation zones, and other features that may affect crop development. Digital Terrain Models (DTM) allow precise analysis of the land’s morphology and the identification of lowlying zones where water naturally accumulates.

Such depressions can lead to major issues, including water stagnation, reduced soil aeration, and increased susceptibility to fungal diseases. Once identified, the exact soil volumes required for leveling can be calculated, enabling accurate estimates of materials, costs, and work duration. Compared with traditional methods—often based on manual measurements or empirical approximations—UAV and GIS approaches reduce errors and optimize resource allocation.

Effective leveling improves the uniform distribution of irrigation water, eliminating zones with excess or insufficient moisture and ensuring that all plants benefit from optimal conditions. In uneven fields, water tends to accumulate in low areas and bypass higher ground, negatively affecting crop development. Leveling mitigates these issues, simplifying irrigation management. Furthermore, mechanized operations such as plowing, seeding, and harvesting become more efficient and less damaging on leveled fields, allowing modern agricultural machinery to operate at full capacity without risks associated with irregular terrain.

Planning leveling operations using UAV data enables continuous monitoring of terrain evolution before, during, and after fieldwork, allowing real-time adjustments. This process can be integrated with intelligent agricultural management systems, including autonomous robots or automated equipment that execute tasks according to digitally generated plans, reducing human error and maximizing productivity. Land preparation thus becomes more precise, efficient, and sustainable, protecting the environment while enhancing production quality.

Variable-Rate Seeding and Differentiated Treatments

Variable-rate seeding and differentiated treatment applications are innovative precision agriculture practices designed to maximize yield while reducing environmental impact. Every parcel of land exhibits significant variability in soil texture, topography, nutrient content, and water or phytosanitary needs, making a uniform “one-size-fits-all” approach inefficient.

UAV-based 3D mapping and GIS analysis enable variable-rate zoning of the field, identifying micro-relief features and altitude variations that influence moisture distribution and water runoff. Multispectral and thermal sensors provide information on crop status and vegetation variability, generating thematic maps that reflect soil characteristics and crop conditions. These maps become key tools for variable-rate seeding, where seed density and distribution are tailored to local conditions.

Fertile zones receive higher seed density, while poorer areas receive smaller quantities, maximizing production potential and reducing waste. Differentiated application of fertilizers and pesticides lowers soil and water pollution, minimizes pest resistance, and protects operator health. Modern equipment equipped with GPS and automated control systems ensures the precise execution of planned strategies, increasing accuracy and process repeatability.

Integrating artificial intelligence and machine learning enables the analysis of large data volumes and the generation of automated or semi-automated recommendations for variable-rate seeding and differentiated treatments. Decisions thus become faster, more precise, and more adaptable to changing conditions, ensuring efficient resource use and supporting sustainable and regenerative agriculture.

BENEFITS AND CHALLENGES

Benefits

The integration of UAV and GIS technologies into agriculture—particularly through the use of 3D terrain mapping—represents one of the most significant innovations in the transition toward Agriculture 5.0. In a period marked by increasing pressure on food systems and intensifying climate challenges, these technologies have the potential to transform agriculture into a more efficient and sustainable system.

One of the key advantages of implementing such technologies is *the increased efficiency in resource use*. Due to the capability of UAVs to collect multispectral, thermal, and visual data, farmers can accurately analyze the conditions of each specific crop zone. This enables them to apply inputs such as water, fertilizers, or pesticides in a differentiated manner, based on the precise needs of the plants. As a result, farmers can reduce waste, optimize costs, and maximize yields, ultimately fostering more efficient land management.

Another major benefit is *the reduction of negative environmental impacts*. The precise application of chemical substances helps prevent soil and groundwater contamination, minimizing pollution risks. Additionally, UAV technologies enable the detection of areas affected by diseases or nutrient deficiencies, thus supporting targeted interventions and avoiding the overuse of toxic substances. These methods also help reduce erosion and protect soil structure.

UAV and GIS technologies further *contribute to enhanced productivity*. They not only *help increase crop yields* but also *improve crop quality*. Continuous vegetation monitoring allows farmers to respond quickly when signs of physiological stress or pathogen attacks are detected. Moreover, these technologies help identify issues such as soil compaction, salinization, or inadequate pH, thereby improving soil conditions and enhancing long-term productive capacity.

These technologies also *support better operational management through real-time data collection*. High-resolution aerial imagery provides farmers with a deeper understanding of terrain and crop dynamics. This enables fast and well-informed decisions, such as adjusting irrigation during drought events or preventing pest infestations.

Another important advantage lies in the *ability to develop a much more detailed and efficient planning system*. The 3D digital models generated via photogrammetry or LiDAR facilitate the analysis of natural water flow, slope gradients, and microdepressions within the terrain. Such data are essential for designing drainage networks, identifying retention zones, or planning land-leveling operations. As a result, costly errors caused by insufficient information can be avoided.

Agricultural digitalization also brings *substantial benefits in terms of traceability and product certification*. Data collected through UAV and GIS technologies can be used to demonstrate compliance with good agricultural practices and to participate in subsidy programs or organic certification schemes. These data can also be shared with business partners, regulatory institutions, and end consumers, strengthening trust in agricultural products.

Worker health and safety are likewise improved by the adoption of UAV technologies. Reducing the need for on-foot inspections over large or hazardous areas—especially under adverse weather conditions—minimizes physical risks. Additionally, drones can be used to apply phytosanitary treatments, thereby *eliminating direct exposure of workers to toxic substances*.

Another significant advantage is *the enhanced climate resilience of farms*. Detailed topographic models, correlated with climatic and vegetation data, enable farmers to anticipate extreme weather events and adopt adaptive measures, such as selecting more resilient crop varieties or adjusting water conservation practices.

Challenges

Despite the substantial benefits, the large-scale implementation of UAV and GIS technologies in agriculture faces several challenges. One of *the most prominent obstacles is the high initial cost*. Acquiring advanced UAV equipment, multispectral or LiDAR sensors, as well as licenses for GIS or photogrammetric processing software, can be prohibitive for small and medium-sized farms. Additionally, *maintenance and data-processing costs may further strain farmers' budgets*, thereby widening disparities between technologically advanced farms and those with limited resources.

The lack of technical expertise in rural areas is another major challenge. Effective use of drones and GIS platforms requires advanced skills in fields such as photogrammetry, multispectral data interpretation, and spatial modeling. Many farms lack access to adequate training or technical support networks, which may lead to improper implementation.

Interoperability among platforms and equipment also represents a significant barrier. UAV-collected data must be compatible with various GIS systems, yet many of these platforms are not fully cross-compatible, reducing efficiency and increasing customization costs.

Digital infrastructure deficiencies in many rural regions further hinder adoption. Without reliable high-speed internet connectivity or access to local data centers, farmers cannot fully capitalize on cloud-based processing or mobile applications.

Data protection and information security are also major concerns. Collecting and storing sensitive data about farmland and agricultural operations can create cybersecurity vulnerabilities, particularly in the absence of proper encryption and protection measures.

Finally, *social acceptance of new technologies* remains an obstacle. Many agricultural communities express reluctance toward automation and digitalization, often perceived as threats to traditional jobs. Therefore, the adoption of these technologies must be supported by educational campaigns and continuous training to ensure a smooth transition toward a digitized agricultural model.

These challenges call for coordinated efforts among authorities, researchers, and farmers to ensure the effective and sustainable implementation of UAV and GIS technologies in agriculture.

THE ROLE IN THE TRANSITION TOWARD AGRICULTURE 5.0

3D mapping technologies using UAVs play a pivotal role in the transition toward Agriculture 5.0, which is characterized by the integration of advanced technologies for a more sustainable, resilient, and ethical agricultural sector. In this digital era, UAVs collect precise data on land, topography, soil moisture, and microclimatic variability, which are essential for developing customized agricultural management strategies. This information is integrated with artificial intelligence (AI), the Internet of Things (IoT), edge computing, and big data, facilitating rapid and efficient agronomic decision-making.

3D mapping enables more efficient resource management through detailed land analysis, helping identify areas with high production potential as well as zones vulnerable to abiotic stress, such as drought or soil erosion. AI algorithms can automatically adjust irrigation, fertilization, and phytosanitary strategies, minimizing losses and maximizing yields. Human–machine collaboration thus becomes a cornerstone of Agriculture 5.0, where autonomous machinery, guided by precise data, executes complex operations—such as variable-rate seeding and zonal treatments—under the supervision of farmers who make data-driven decisions.

Another major benefit of 3D mapping technologies is the promotion of sustainable agricultural management. These technologies help prevent soil and water pollution, manage resource consumption efficiently, and support regenerative agriculture practices. They also facilitate rapid adaptation to climate change, providing farmers with tools to respond more effectively to extreme weather events. Furthermore, the digitalization of farmland contributes to transparency and ethical practices in agriculture, ensuring data protection and equitable access to technologies.

The integration of IoT and edge computing in agriculture enhances system responsiveness by enabling real-time monitoring of critical factors, such as soil moisture and pest presence. The collected data are processed locally, allowing for immediate and autonomous field interventions. 3D mapping provides the foundational framework for these systems, correlating sensor information with geographical positions and topographic conditions, thereby enabling adaptive and precise management.

From an economic perspective, UAV-GIS technologies can reduce operational costs by optimizing resource use, improving labor efficiency, and minimizing losses. They also support smallholder farmers by providing access to tools and information that were previously available only to large-scale operations, fostering the development of rural communities. At the same time, the digital transformation demands a cultural shift, requiring digital literacy and collaboration among the public, private, and academic sectors to support the transition toward Agriculture 5.0.

CONCLUSIONS AND FUTURE DIRECTIONS

The transition toward Agriculture 5.0 entails the integration of UAV-GIS technologies, which facilitate farmland digitalization and support intelligent, data-driven decision-making based on precise measurements and advanced analyses. 3D mapping provides a detailed understanding of the spatial variability of agricultural lands, enabling adaptive management of resources such as water, soil, and nutrients, thereby increasing efficiency, reducing environmental impact, and maximizing crop productivity.

The integration of data with artificial intelligence and machine learning systems allows for the development of personalized agricultural strategies, tailored to local conditions and climate, enhancing the resilience of agricultural systems. Agriculture 5.0 also relies on human–machine collaboration, where drones and autonomous machinery use 3D maps to perform complex operations with high precision and efficiency, promoting sustainability and responsibility toward the environment and society.

Challenges in implementing these technologies include high costs, the need for technical expertise, and interoperability between UAV, GIS, and agricultural machinery platforms. These obstacles can be addressed through public policies, training programs, and open standards, fostering collaboration among stakeholders.

Future prospects involve the development of advanced multispectral and LiDAR sensors, big data analytics, increasingly sophisticated autonomous systems, broader access to technology for small and medium-sized farms, and the integration of sustainability, ethical, and social inclusion principles.

Considering all these aspects, it is evident that farmland digitalization through UAV-GIS is essential for smart, sustainable, and resilient agriculture capable of addressing economic, social, and climatic challenges. Investments in research, education, and digital infrastructure are crucial to ensuring a prosperous future for agriculture.

REFERENCES

Bissadu, K.D., Sonko, S., Hossain, G. (2025). *Society 5.0 enabled agriculture: Drivers, enabling technologies, architectures, opportunities, and challenges*. Information Processing in Agriculture, 12(1):112-124, https://doi.org/10.1016/j.inpa.2024.04.003.

Bwambale, E., Wanyama, J., Adongo, T.A., Umukiza, E., Ntole, R., Chikavumbwa, S.R., Sibale, D., Jeremaih, Z. (2025). *A review of model predictive control in precision agriculture*. Smart Agricultural Technology, 10: 100716, https://doi.org/10.1016/j.atech.2024.100716.

Canicattì, M., Vallone, M. (2024). *Drones in vegetable crops: A systematic literature review*. Smart Agricultural Technology, 7: 100396, https://doi.org/10.1016/j.atech.2024.100396.

Călina, A., Călina, J. (2019). *Research regarding the agriproductive properties of the typical reddish preluvosol between Jiu and Olt rivers and its evolution from 1997-2017 in farms and agritouristic households.* Romanian agricultural research, 36:251-261.

Călina, J., Călina, A. (2019). *Evolution of the mollic reddish preluvisol in a Romanian riverine region and the assessment of its agro-productive properties in farms and agro-touristic households.* Environmental Engineering & Management Journal, 18(12):2729-2738.

Călina, J., Călina, A. (2021). *Study on designing municipal technical network maps for an agricultural company with the help of a GIS.* AgroLife Scientific Journal, 10(2). https://doi.org/10.17930/AGL202123.

Călina, J., Călina, A. (2021). *Study on the development of a GIS for improving the management of water network for an agricultural company.* Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 21(4), ISSN 2284-7995, E-ISSN 2285-3952.

Călina, J., Călina, A., Iancu, T., Miluț, M., Croitoru, A. C. (2022). *Research on the Influence of Fertilization System on the Production and Sustainability of Temporary Grasslands from Romania*. Agronomy, 12(12), 2979. https://doi.org/10.3390/agronomy12122979.

Călina, J., Călina, A., Croitoru, A. (2025). *Research on the management of the main chemical properties of chromic luvisols from farms/households agritouristic in dolj, in the period 1995-2021*. AgroLife Scientific Journal, 12(2):60-68. https://doi.org/10.17930/AGL202328.

Hansman, R.J., Ring, U. (2019). *Workflow: From photo-based 3-D reconstruction of remotely piloted aircraft images to a 3-D geological model*. Geosphere, 15(4):1393-1408, https://doi.org/10.1130/GES02031.1

Mandal, S., Yadav, A., Panme, F.A., Devi, K.M., Kumar, S.M.S. (2024). *Adaption of smart applications in agriculture to enhance production*. Smart Agricultural Technology, 7:100431, https://doi.org/10.1016/j.atech.2024.100431.

Pop, S.B., Sălăgean, T., Șuba, E.E., Pop, N., Rusu, T. (2024). *Application of UAS Technology for the Development of Precision Agriculture*. Bulletin of the University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca Forestry and Cadastre, 81(1):8-18.

Shamshiri, R.R., Hameed, I.A., Balasundram, S.K., Ahmad, D., Weltzien, C., Yamin, M. (2018). *Fundamental Research on Unmanned Aerial Vehicles to Support Precision Agriculture in Oil Palm Plantations*, Agricultural Robots - Fundamentals and Applications, DOI: 10.5772/intechopen.80936.

Uztürk, D., Büyüközkan, G. (2024). *Industry 4.0 technologies in Smart Agriculture: A review and a Technology Assessment Model proposition*. Technological Forecasting and Social Change, 208: 123640, https://doi.org/10.1016/j.techfore.2024.123640.

Vangu, G.M., Miluț, M., Croitoru, A., Croitoru, I., Dinucă, N.C. (2022). *The use of drones and sensors in agriculture*. Annals of the University of Craiova - Agriculture, Montanology, Cadastre Series), Vol. 52/2/2022.

***https://www.cohga.com/diy-drone-mapping-workshop-for-agriculture/, last accesed on 07 october 2025.