MULTIFUNCTIONAL APPLICATIONS OF UNMANNED AERIAL VEHICLES (UAVS) IN ECOSYSTEM MANAGEMENT: AGRICULTURE AND FORESTRY PERSPECTIVE

Mateusz Jakubiak[1,2,3]*, Katarzyna Sroka[1,4], Anastasiia Kovalova[1]

[1]Faculty of Geo-Data Science, Geodesy, and Environmental Engineering, AGH University of Krakow, Krakow 30-059, Poland

[2]Faculty of Sciences and Technology, University of Cape Verde, Praia 7943-010, Cape Verde

[3]Department of Archaeology, Conservation, Restoration and Heritage, Polytechnic Institute of Tomar, Tomar 300-313, Portugal

[4]Department of Ichthyobiology and Fishery Management in Gołysz, Polish Academy of Sciences, Zaborze 43-520, Poland

Abstract

Forest and agricultural ecosystems are crucial to human well-being. Advanced technologies are frequently employed to reduce costs and increase the efficiency of forest and agricultural land management. The article discusses selected examples of the use of unmanned aerial vehicles (UAVs) in precision agriculture and forestry. Due to their mobility, UAVs are used in monitoring, research, and precision agronomic treatments. The potential for using UAVs has increased significantly over the last decade, driven by the development of new technologies, miniaturization, and the availability of multispectral and thermal cameras. The use of UAVs in forest and crop monitoring is beneficial for assessing their health, plant condition, and identifying potential threats, which enables the planning of effective protection strategies and the immediate implementation of corrective measures. The relatively low purchase and operating costs of UAVs enable the observation of changes in agricultural and forest ecosystems and the rapid implementation of precise intervention actions (e.g., fertilization, pest control).

Keywords: *drones, remote sensing, fertilization, pests, multispectral and thermal cameras*

1. INTRODUCTION

Forest and agricultural ecosystems are crucial to human well-being (Castle *et al.*, 2021; Wang, Zhang and Cui, 2021). Apart from the obvious provision of products such as wood or food (so-called provisioning services), these ecosystems also provide a range of regulatory, cultural, and supporting ecosystem services (Jakubiak, 2020; Jakubiak and Chmielowski, 2020). The quality of ecosystem services provided to humans largely depends on the health of the habitat. The condition of an ecosystem is determined primarily on the basis of biotic characteristics, but it can also be assessed on the basis of abiotic and landscape features (Turner and Gardner, 2015). Vegetation can serve as a direct indicator of ecosystem health. Therefore, monitoring the condition of ecosystems, their health, and biodiversity is crucial in forest management and plant production (Bazzo *et al.*, 2024). Advanced technologies are frequently employed to reduce costs and increase the efficiency of forest and agricultural land management. Rapid technological progress is contributing to the development of tools that increasingly support the monitoring and sustainable management of agricultural and forestry crops. Unmanned Aerial Vehicles (UAVs), also known as drones, are increasingly being used for this purpose. UAVs are autonomous or remotely controlled flying systems used to collect environmental data from the air (López and Mulero-Pázmány, 2019) or perform a range of crop-related activities such as precision spraying and fertilization. Due to their advantages and range of applications, in many cases, UAVs can be used as an alternative or supplement to traditional methods such as satellite Earth observation or ground-based in situ measurements.

This manuscript addresses technical aspects of the rapidly advancing UAV technology. Sensors and cameras used in monitoring agricultural and forest ecosystems are analyzed. Furthermore, selected examples of the use of UAVs in precision agriculture and forestry are presented.

2. MATERIALS AND METHODS

The study reviewed the literature available in databases such as Google Scholar and Scopus, taking into account both original research papers and review articles. Given the rapid development of UAV technologies over the past decade, the focus was primarily on recent literature. The applications of unmanned aerial vehicles in forest and agricultural monitoring and management activities were analyzed.

3. RESULTS AND DISCUSSION

UAVs vary greatly in size, design, and application capabilities. However, drones are typically equipped with advanced sensors to protect against damage, precise navigation systems, remote links for data transmission, and autonomous pilot technology. Advances in equipment allow for increasingly easier autonomous flights, expanded applications, and the collection of more precise data (Tmušić *et al.*, 2020). Due to their design, UAVs can be divided into two basic categories: more popular rotary-wing and fixed-wing. Rotary-wing UAVs, most often quadcopters, are capable of vertical takeoff and landing (VTOL) and of hovering in a fixed position. Thanks to these capabilities, they are perfect for missions that need precise positioning, spot inspections, or flying over hard-to-reach areas, like forests or built-up areas (Bayomi and Fernandez, 2023). Multirotor UAVs tend to have simpler configurations and lower operating costs (Chen, Maurer and Gong, 2025). Users report that their main disadvantages include short flight time (usually 30–40 minutes) due to high energy consumption and low payload capacity (Mohsan *et al.*, 2022). Fixed-wing UAVs, although less maneuverable, offer significantly longer flight times (up to several hours) and greater range. This makes them more suitable for longer missions involving the monitoring of objects such as power lines, rivers, or large areas. The disadvantage of this design is the need for a suitable take-off and landing area and limited maneuverability in narrow spaces (Chen, Maurer and Gong, 2025). Each type of platform has specific advantages and disadvantages, which vary depending on the requirements of specific applications. The decision to use a fixed-wing or rotary-wing UAV should be based primarily on the size of the survey area, the complexity of the terrain, and the sensors with which the UAVs can be equipped. There is no universal classified standard for UAS based on weight. The most common classification methods refer to the maximum take-off mass (MTOM). European Union regulations, in force since 2024, have introduced a distinction between MTOM for flights in the open category into four weight categories (< 250g, <900g, <4kg, and <25kg) (EU Commission, 2019). The Civil Aviation Safety Authority (CASA), which is the Australian government body responsible for regulations of aviation safety, classify UAVs by weight, with categories: micro (less than 250g), very small (250g to 2kg), small (2kg to 25kg), and medium (25kg to 150kg). Some authors provide their own weight-based categorization proposals: micro (less than 5 kg); mini (less than 30 kg); and tactical (less than 150 kg) (Colomina and Molina, 2014). Advances in battery manufacturing technology have enabled the introduction of lighter and more efficient power sources. Thanks to new lightweight composite materials, drone designs have evolved, leading to reduced weight (Shakhatreh et al., 2019). The choice of the appropriate type of UAV depends on the type of space in which the mission will take place and the requirements regarding the length and purpose of the mission.

Although the first commercial drones were characterized by very high purchase costs, short flight times, and limited payloads, over the last decade, UAVs have undergone extensive improvements and have become more widespread thanks to declining prices (Shakhatreh *et al.*, 2019; Delavarpour *et al.*, 2021). With the development of drone design and manufacturing technologies, remote sensing methods have also developed rapidly. The popularity of these technologies derives from their effectiveness in monitoring changes in the quality of individual environmental elements (Mazur *et al.*, 2024). They are used to monitor biodiversity and protect species (Bazzo *et al.*, 2024). Until UAVs become widespread, data was mainly obtained from satellite remote sensing. Such data is useful in determining the spatial extent or fragmentation of habitats and vegetation types (Kissling et. al. 2024). However, UAVs are more effective for providing environmental information on a smaller scale, monitoring local habitat changes, or monitoring individual species of flora (Jakubiak, 2024). Along with the increasing availability of UAVs, low-level photogrammetry is developing rapidly. The use of UAVs to obtain images significantly speeds up field work and does not require direct access to the monitored area (Pyka, Wiącek and Guzik, 2020), which is a significant advantage compared to in-situ observations. Data collection based on field surveys can be significantly complicated due to the scale of the area under study, the costs of conducting monitoring studies, and the inability to access the study sites (Kamali *et al.*, 2024). UAVs enable the collection of high-resolution data from inaccessible areas such as marshes, dense vegetation, and forest canopies. Therefore, the use of UAVs for monitoring significantly increases the potential for accurate mapping of plant diversity in herbaceous communities, shrubbery, and forest areas (Dainelli *et al.*, 2021; Rossi *et al.*, 2022). UAVs also solve the problem of cloud cover, which usually limits satellite monitoring in conditions of heavy cloud cover (Bazzo *et al.*, 2024). While strong winds pose more problems for UAV missions, compared to photogrammetry from manned aircraft, the technology is less sensitive to weather conditions (Pyka, Wiącek and Guzik, 2020). Furthermore, conducting an inspection by plane is more expensive and requires the direct involvement of at least two people (a pilot and a camera operator).

The basis for precise monitoring of crops is systems of sensors mounted on UAVs. In general, the equipment can be divided into two types: imaging and non-imaging sensors. Image sensors register data that can be processed into visual or spectral images. These include multispectral cameras for analyzing vegetation and moisture, hyperspectral cameras for detailed spectral characteristics, infrared thermal cameras for detecting temperature differences, and RGB digital cameras for high-resolution imaging, often equipped with a very good zoom (Gašparović, Medak and Miler, 2017; Sun *et al.*, 2021, 2023; Chen, Maurer and Gong, 2025).

The RGB camera is a standard system that records the visible red (R), green (G), and blue (B) spectra with wavelengths from 400 to 700 nm. Due to its wide availability, it is one of the most popular sensors mounted on UAVs used in agriculture and forestry. Modern devices have been significantly miniaturized, their weight is reduced, and they are characterized by simple calibration and easy data processing (Santini *et al.*, 2019; Sun *et al.*, 2021). In agriculture, images from RGB cameras allow for the generation of high-resolution orthophotos. They are also useful for modeling vegetation structure to estimate plant height, crop biomass, Leaf Area Index (LAI), vegetation cover, yield estimation, lodging, and for obtaining other parameters related to active photosynthetic plant cover, such as Green Area (GA), Greener Green Area (GGA), and the Crop Senescence Index (CSI) (Santini *et al.*, 2019; Tanaka *et al.*, 2024). In forestry, the use of RGB cameras allows for the identification and classification of individual trees through crown segmentation and image analysis. The images can also be used to estimate tree height, crown density, and vegetation cover as well as to approximate wood volume based on height and cover measurements (Santini *et al.*, 2019). This estimation method is applied for the rapid assessment of stand condition or for monitoring growth in tree plantations.

Along with using digital RGB cameras, combining multispectral sensors with UAVs has also helped advance research on forest and agricultural vegetation. Multispectral cameras mounted on UAVs record several narrow bands of light, usually RGB, red-edge, and near-infrared (NIR). Such sensors enable the calculation of vegetation indices such as Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI), Soil Adjusted Vegetation Index (SAVI), and Normalized Difference Red Edge (NDRE), which are strongly correlated with plant condition, biomass, and water stress. The multispectral sensors are more accurate in mapping land cover and changes in vegetation, monitoring vegetation changes, finding bare soil, and dead matter classes (Dainelli *et al.*, 2021; Delavarpour *et al.*, 2021; Sun *et al.*, 2023; Chen, Maurer and Gong, 2025). Multispectral imagery is used in agriculture and forestry to precisely assess plant health (pests, diseases), predict yields, and evaluate water stress or excess/deficiency of nitrogen in the soil, thanks to the information provided by calculated vegetation indices. Multispectral cameras allow better differentiation between plant varieties and environmental conditions than RGB cameras (Santini *et al.*, 2019). Unmanned aerial vehicles equipped with multispectral cameras enable the monitoring of ecological succession, analysis of changes in regenerating forest stands, identification of invasive species, and analysis of tree phenology.

Thermal sensors, also known as thermal imaging cameras, capture invisible infrared radiation emitted by objects. These cameras enable the creation of thermal images that visualize the surface temperature of objects. Monitoring changes in surface temperature across a studied area can reveal information not visible in multispectral images (Chen, Maurer and Gong, 2025). Infrared radiation detection cameras allow for mapping the temperature of plant surfaces and soil, which is crucial for assessing water stress, plant physiology, identifying disease outbreaks, and forest fire (Santini *et al.*, 2019; Sun *et al.*, 2021). In agriculture, thermal UAVs are primarily used for early detection of water shortages by detecting reduced transpiration and elevated plant canopy temperatures. Therefore, in crop production, thermal UAVs are used for precise drought monitoring, supporting irrigation decisions, and water resource management. They can assist with irrigation planning by detecting excessively dry or overheated areas, improving precision, and increasing water conservation. Thermal sensors are useful for detecting opposite terrain anomalies with high moisture content, which typically appear cooler in the image due to evaporative cooling (Chen, Maurer and Gong, 2025). In forestry, UAV-based thermal cameras aid not only in assessing tree water stress but also in detecting forest fires or hot spots in their early stages. Combined with multispectral imagery, they enable the rapid detection of at-risk areas and support rescue operations and forest health monitoring following droughts or fires.

LiDAR (Light Detection and Ranging) technology in UAV systems is considered a non-imaging sensor; it is an example of a depth sensor. LiDAR enables the precise acquisition of three-dimensional data concerning vegetation structure, such as plant height, tree crown structure, leaf density, and terrain topography. The laser pulses emitted by the sensor reflect off surfaces, creating accurate point clouds. These point clouds form the basis for generating various models and indices, including Canopy Height Models (CHM), Digital Terrain Models (DTM), Leaf Area Index (LAI), and canopy density, biomass estimation (Wang *et al.*, 2021). In agriculture, UAV LiDAR is particularly effective for the precise measurement of plant height and biomass. In forestry, UAV LiDAR not only allows for forest stand inventory but also for individual tree detection (ITD), assessment of canopy density, and the estimation of standing biomass volume (Sun *et al.*, 2023; Soraya *et al.*, 2025).

Beyond remote sensing and imaging, unmanned aerial vehicles are widely utilized in practical agrotechnical operations such as precision seeding, fertilization, pesticide spraying, and spot-dosing systems for biological or chemical agents. In precision agriculture, UAVs equipped with accurate spraying systems enable variable rate application (VRA) of fertilizers, crop protection products, and growth regulators. Depending on the installed equipment, drones can precisely dispense liquid substances (spraying) or granules and seeds (spreading). UAV sprayers are equipped with nozzles that allow for real-time dose adjustment, along with altitude and flight speed sensors. This ensures a consistent liquid flow and improves application uniformity (Su *et al.*, 2022; Guebsi, Mami and Chokmani, 2024). UAV fertilizer spreaders feature rate regulation systems that effectively control the fertilizer dose based on local needs. The automated dispensing of granules allows for site-specific fertilizer management. This precise dosing optimizes fertilizer utilization, prevents over-fertilization, and leads to improved yields and reduced costs (Song *et al.*, 2021, 2023; Gowtham *et al.*, 2024). In forestry, UAVs are also used for precise spraying of chemical plant protection products (e.g., pest control), spreading seed and biological agents. They are also used in the replenishment of young stands after felling. Seed drone technologies and micro-dosing systems for nutrient application are becoming increasingly popular in reforestation. Drones can spread seed capsules or mycorrhizal preparations evenly and precisely based on the terrain's topography (Ferreira *et al.*, 2023; Liu *et al.*, 2023; Guebsi, Mami and Chokmani, 2024). Thanks to UAV technologies, biological pest control can be achieved by releasing beneficial insects, predators, and parasites to target crop pests. Aerial-based biocontrol of crops ensures more efficient distribution of biological agents than traditional application techniques. Pest populations can be managed even when located in areas inaccessible to chemical agents. Additionally, it can significantly reduce pesticide use (Delavarpour *et al.*, 2021). By integrating UAV platforms with information from multispectral cameras (e.g., NDVI maps), precise application of nitrogen fertilizers and pesticides can be achieved based on the actual needs of the vegetation. This approach reduces chemical use, minimizes the environmental impact of agriculture, and lowers production costs (Guebsi, Mami and Chokmani, 2024).

4. CONCLUSIONS

Unmanned Aerial Vehicles (UAVs) represent a rapidly evolving technological tool that significantly enhances the precision and efficiency of monitoring and managing forest and agricultural ecosystems. Their increasing accessibility, miniaturization of equipment, and development of lightweight materials have made UAVs a viable and cost-effective alternative to traditional ground-based and satellite observation methods.

Equipped with a wide range of imaging and non-imaging sensors—such as RGB, multispectral, and thermal cameras, as well as LiDAR—UAVs enable the acquisition of high-resolution spatial data critical for assessing vegetation health, monitoring biodiversity, estimating biomass, detecting plant diseases, and evaluating environmental stress factors such as drought or nutrient deficiency. These capabilities support both research and operational management in precision agriculture and sustainable forestry.

The integration of UAVs with advanced analytical tools (e.g., vegetation indices or 3D terrain models) allows for accurate mapping, yield forecasting, and informed decision-making. Furthermore, UAVs are increasingly used not only for data collection but also for direct interventions, including site-specific seeding, spraying, fertilization, and biological pest control.

Given their versatility, UAVs are becoming indispensable for sustainable ecosystem management. However, their effectiveness depends on appropriate platform selection, sensor calibration, and alignment with the specific needs of the monitoring objectives. As UAV technologies continue to evolve, their role in environmental research and resource management is expected to expand, contributing to more resilient and adaptive agricultural and forestry systems.

ACKNOWLEDGMENTS

This research project was supported by the program “Excellence initiative—research university” for the AGH University of Krakow.

REFERENCES

1. Bayomi, N & Fernandez, JE 2023, “Eyes in the sky: Drones applications in the built environment under climate change challenges”, *Drones*, vol. 7, no. 10.
2. Bazzo, COG, Kamali, B, Vianna, MdS, Behrend, D, Hueging, H, Schleip, I, Mosebach, P et al. 2024, “Integration of UAV-sensed features using machine learning methods to assess species richness in wet grassland ecosystems”, *Ecological Informatics*, vol. 83, p. 102813.
3. Castle, SE, Miller, DC, Ordonez, PJ, Baylis, K & Hughes, K 2021, “The impacts of agroforestry interventions on agricultural productivity, ecosystem services, and human well-being in low- and middle-income countries: A systematic review”, *Campbell Systematic Reviews*, vol. 17, no. 2. p. e1167.
4. Chen, B, Maurer, J & Gong, W 2025, “Applications of UAV in landslide research: A review”, *Landslides*, Springer Nature.
5. Colomina, I & Molina, P 2014, “Unmanned aerial systems for photogrammetry and remote sensing: A review”, ISPRS *Journal of Photogrammetry and Remote Sensing*, vol. 92, pp. 79–97.
6. Dainelli, R, Toscano, P, Di Gennaro, SF & Matese, A 2021, “Recent advances in unmanned aerial vehicles forest remote sensing—a systematic review. Part II: Research applications”, *Forests*, vol. 12, no. 4. P. 327.
7. Delavarpour, N, Koparan, C, Nowatzki, J, Bajwa, S & Sun, X 2021, “A technical study on UAV characteristics for precision agriculture applications and associated practical challenges”, Remote Sensing, vol. 13, p. 1204.
8. EU Commission 2019, Commission implementing regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft.
9. Ferreira, JF, Portugal, D, Andrada, ME, Machado, P, Rocha, RP & Peixoto, P 2023, “Sensing and artificial perception for robots in precision forestry: A survey”, *Robotics*, vol. 12, p. 139.

10. Gašparović, M, Medak, D & Miler, M 2017, "Geospatial monitoring of green infrastructure – case study Zagreb, Croatia", *SGEM Conference Proceedings*, vol. 17, no. 33, pp. 569–576.
11. Gowtham, S, Shirwal, S, Murali, M & Sripriyanka, SN 2024, "Application UAV based granular fertilizer spreader for paddy", *Just Agriculture*, vol. 4, no. 12, pp. 39–45.
12. Guebsi, R, Mami, S & Chokmani, K 2024, "Drones in precision agriculture: A comprehensive review of applications, technologies, and challenges", *Drones*, vol. 8, p.686.
13. Jakubiak, M 2020, "Ewolucja usług ekosystemowych jako nowego podejścia do kapitału naturalnego", in X Kongres Ekonomistów Polskich, Ekonomiści dla rozwoju – sesja III „Sfera regulacji gospodarki", Ekonomiczne Polskie Towarzystwo, Warszawa, pp. 175–183.
14. Jakubiak, M 2024, "Wykorzystanie bezzałogowych statków powietrznych do retardacji przekształcania zasobów środowiska", *Polish Journal for Sustainable Development*, vol. 28, no. 1, pp. 107–112.
15. Jakubiak, M & Chmielowski, K 2020, "Identification of urban water bodies ecosystem services", Acta Scientiarum Polonorum Formatio Circumiectus, vol. 19, no. 3, pp. 73–82.
16. Kamali, B, Ahmadi, SH, Gaiser, T, Buddeberg, M & Nendel, C 2024, "Quest to find compromised spatial and temporal resolutions for integrating remote sensing data with an agro-ecosystem model for grasslands", *International Journal of Applied Earth Observation and Geoinformation*, vol. 128, p. 103705.
17. Kissling, WD, Shi, Y, Wang, J, Walicka, A, George, C, Moeslund, JE, & Gerard, F 2024. "Towards Consistently Measuring and Monitoring Habitat Condition with Airborne Laser Scanning and Unmanned Aerial Vehicles.", *Ecological Indicators,* vol. 169, p. 112970.
18. Liu, H, Chen, Z, Wang, Z & Li, J 2023, "An effective precision afforestation system for UAV", *Sustainability*, vol. 15, p. 2212.
19. López, JJ & Mulero-Pázmány, M 2019, "Drones for conservation in protected areas: Present and future", *Drones*, vol. 3, no. 1, pp. 1–23.
20. Mazur, R, Kowalewski, Z, Głowienka, E, Santos, L & Jakubiak, M 2024, "Sustainability in aquatic ecosystem restoration: Combining classical and remote sensing methods for effective water quality management", *Sustainability*, vol. 16, no. 9.
21. Mohsan, SAH, Khan, MA, Noor, F, Ullah, I & Alsharif, MH 2022, "Towards the unmanned aerial vehicles (UAVs): A comprehensive review", *Drones*, vol. 6, p. 147.
22. Pyka, K, Wiącek, P & Guzik, M 2020, "Surveying with photogrammetric unmanned aerial vehicles", *Archives of Photogrammetry, Cartography and Remote Sensing*, vol. 32, p. 79.
23. Rossi, C, Kneubühler, M, Schütz, M, Schaepman, ME, Haller, RM & Risch, AC 2022, "Spatial resolution, spectral metrics and biomass are key aspects in estimating plant species richness from spectral diversity in species-rich grasslands", *Remote Sensing in Ecology and Conservation*, vol. 8, no. 3, pp. 297–314.
24. Santini, F, Kefauver, SC, Resco de Dios, V, Araus, JL & Voltas, J 2019, "Using unmanned aerial vehicle-based multispectral, RGB and thermal imagery for phenotyping of forest genetic trials: A case study in Pinus halepensis", *Annals of Applied Biology*, vol. 174, no. 2, pp. 262–276.
25. Shakhatreh, H, Sawalmeh, AH, Al-Fuqaha, A, Dou, Z, Almaita, E, Khalil, I, Othman, NS, Khreishah, A & Guizani, M 2019, "Unmanned aerial vehicles (UAVs): A survey on civil applications and key research challenges", *IEEE Access*, vol. 7, pp. 48572–48634.
26. Song, C, Liu, L, Wang, G, Han, J, Zhang, T & Lan, Y 2023, "Particle deposition distribution of multi-rotor UAV-based fertilizer spreader under different height and speed parameters", *Drones*, vol. 7, p. 425.
27. Song, C, Zhou, Z, Zang, Y, Zhao, L, Yang, W, Luo, X, Jiang, R et al. 2021, "Variable-rate control system for UAV-based granular fertilizer spreader", *Computers and Electronics in Agriculture*, vol. 180, p. 105832.
28. Soraya, E, Umarhadi, DA, Wardhana, W & Ardiansyah, F 2025, "Aerial imagery and UAV-LiDAR data fusion for quantifying aboveground carbon stock of teak plantation", *Ecological Engineering & Environmental Technology*, vol. 26, no. 2, pp. 178–192.
29. Su, D, Yao, W, Yu, F, Liu, Y, Zheng, Z, Wang, Y, Xu, T & Chen, C 2022, "Single-neuron PID UAV variable fertilizer application control system based on a weighted coefficient learning correction", *Agriculture*, vol. 12, p. 1019.

30. Sun, H, Yan, H, Hassanalian, M & Zhang, J 2023, "UAV platforms for data acquisition and intervention practices in forestry: Towards more intelligent applications", *Aerospace*, vol. 10, p. 317.
31. Sun, Z, Wang, X, Wang, Z, Yang, L, Xie, Y & Huang, Y 2021, "UAVs as remote sensing platforms in plant ecology: Review of applications and challenges", *Journal of Plant Ecology*, vol. 14, no. 6, pp. 1003–1023.
32. Tanaka, T, Tashi, ST, Wang, S, Jørgensen, JR, Gentili, M, Vidal, AZ, Mortensen, AK et al. 2024, "Review of crop phenotyping in field plot experiments using UAV-mounted sensors and algorithms", *Drones*, vol. 8, no. 212, pp. 1–21.
33. Tmušić, G, Manfreda, S, Aasen, H, James, MR, Gonçalves, G, Ben-Dor, E, Brook, A et al. 2020, "Current practices in UAS-based environmental monitoring", *Remote Sensing*, vol. 12, p. 1001.
34. Turner, MG & Gardner, RH 2015, *Landscape ecology in theory and practice: Pattern and process*, 2nd edn, Springer-Verlag, New York.
35. Wang, B, Zhang, Q & Cui, F 2021, "Scientific research on ecosystem services and human well-being: A bibliometric analysis", *Ecological Indicators*, vol. 125, p. 107449.
36. Wang, T, Liu, Y, Wang, M, Fan, Q, Tian, H & Qiao, X 2021, "Applications of UAS in crop biomass monitoring: A review", Frontiers in Plant Science, vol. 12, April, pp. 1–16.Huffman, LM 1996, "Processing whey protein for use as a food ingredient", *Food Technology*, vol. 50, no. 2, pp. 49-52.