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Review

Drone-Related Agrotechnologies for Precise Plant Protection in Western Balkans: Applications, Possibilities, and Legal Framework Limitations

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Abstract: Modern agriculture necessitates the use of techniques and tools that pollute the environment less and improve the safety of food and feed production. In the field of plant protection, drones are attracting increasing attention due to their versatility and applicability in a variety of environmental and working conditions. Drone crop spraying techniques offer several advantages, including increased safety and cost effectiveness through autonomous and programmed operations based on specific schedules and routes. One of the main advantages of using drones for plant protection is their ability to monitor large areas of crops in a short amount of time. In addition to crop protection management, using drones for augmentative biocontrol facilitates the distribution of beneficial organisms to the exact locations where they are required, which can increase the effectiveness of biocontrol agents while reducing distribution costs. In this context, given the very limited commercial use of drones in the Western Balkans' agri-food sector, the use of drones in the agri-food industry is a topic that needs to be elaborated on and highly promoted. Additionally, the specific legal regulations in Serbia that currently limit the use of drones in agriculture must be outlined. Conventional crop production is still significantly more prevalent in Serbia, but given the region's continuous technological progress, there is no doubt that farmers' education and future investments in precision agriculture will most likely increase the use of state-of-the-art technologies and drones in agriculture.

Keywords: climate smart agriculture; biocontrol agents; drones; legislative; pesticides; technologies

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1. Introduction

The Western Balkans region covers an area of approximately 218,800 km^2 and includes the Republic of Serbia, Albania, Bosnia and Herzegovina, Montenegro, and the Republic of North Macedonia. Agriculture is a significant economic sector in Western Balkans, representing a share of nearly 10% of the gross domestic product (GDP), owing to its favorable agro-ecological conditions (https://agriculture.ec.europa.eu/, accessed on 7 August 2023). As in many Western Balkan countries (WBC), almost half the population live in rural areas. Officially, almost one fifth of the workforce is employed in agriculture. In recent years, the share of agriculture in Serbia's GDP has increased and is now twice as high as that of the new EU members from Central and Eastern Europe (www.stat.gov.rs/en-us, accessed on 12 April 2023). Crop production accounts for the largest share of the value of agricultural production, comprising around 67% [1]. The primary economic crops cultivated in WBC are corn, wheat, sunflower, sugar beet, and soybeans [2]. However, the current use of approximately 8.6 million hectares of agricultural land, while providing significant economic benefits, also results in many unintended consequences (https://agriculture.ec.europa.eu/, accessed on 7 August 2023). Large areas of crop cultivation are very conducive to the reproduction of certain pests, which are tropically closely related to specific crops and cause large economic losses in food production [3]. To reduce these losses, pest control management includes various methods and techniques that prevent the action or minimize the impact of agricultural pests. Due to their relatively low cost and ease of application, chemical insecticides are still the main method of pest control used in WBC, despite being proven to impact negatively on the environment. Excessive use of insecticides can lead to residues in crop yields, which can have direct or indirect impacts on human health through the food chain. Moreover, the drift of pesticides during their application or runoff can be toxic to a range of organisms in the soil, waterways, and beyond, including birds, fish, and beneficial insects [4].

As the scale and production of agriculture reach new global records, society's environmental awareness is, fortunately, also on the rise [5]. In modern and environmentally conscious societies, there is a growing demand for high-quality food production without the presence of pesticide residues and other harmful substances. There is also an ecological issue underlying the use of renewable energy sources and the preservation of natural resources and the environment. The modern trend of sustainable agricultural production imposes the need to change the technological process of production with the application of techniques and the usage of tools that pollute the environment less and contribute to health security in general [5]. Numerous studies and social initiatives are calling for conversion to more sustainable agricultural practices due to their favorable effect on ecosystems, biodiversity, and human health [6]. An approach that supports such initiatives is the concept of agricultural management based on the application of information technologies in agriculture, also known as precision agriculture [7]. Precision agriculture, or precision farming, can be defined as a process of agricultural production that includes the application of information technologies and various types of sensors, satellite navigation, the monitoring of working machines, the analysis of collected data, and the decision-making process [7]. Such an approach has clear advantages for optimizing production efficiency and increasing quality, as well as for minimizing environmental impact and risk. In the field of precision agriculture, one tool is gaining popularity due to its versatility and applicability in different environmental and working conditions. This particular interest has recently been devoted to the use of lightweight unmanned aircraft systems (UAS) or unmanned aerial vehicles (UAVs), also known as drones, which were originally developed for military purposes but are now frequently used in civil and research applications. In the last 20 years, the use of drones in different natural resource sectors has increased, including environmental biology, agriculture, agroforestry, and forestry [8–12]. The use of drones in various areas of industry is growing rapidly, which consequently leads to their development. The trend for further improvements of drones in the agri-food sector, along with the automatization of agricultural production, has also been recognized and exploited by the research and business communities [13]. The first reports of drones in agriculture appeared around 1998, and their numbers have grown dramatically in the last decade. Until 2020, the global drone market value was around USD 6.8 billion, and it is expected to reach a value of USD 14.3 billion by 2028 [11]. In agriculture, UAS can not only improve the speed and efficacy of pest monitoring, but they may also be invaluable to pest management as a less expensive means of targeted application of insecticides, biocontrol agents, or even sterile insects to disrupt pest reproduction [11]. In terms of its effectiveness, even the United Nations recently highlighted the potential benefits of UAS use in agriculture for monitoring and protecting agriculture, forest, and fishery resources [14].

Given the widespread use of chemical crop protection, it is imperative to start transitioning from traditional and conventional agricultural techniques to innovative and modern tools in WBC. Such tools can enable the controlled and justified application of chemical agents with an emphasis on the use of alternative methods for pest control, such as biological control measures. In this context, the use of drones in the agri-food industry is a topic that needs to be elaborated on and highly promoted, considering the very scarce commercial usage of drones in agriculture in this part of Europe. Despite its location at the south-eastern border of Europe, WBC have yet to fully utilize the potential of modern agricultural tools, such as drones. Therefore, it is crucial to explore the many potential applications of drones in regular agricultural practices, including crop monitoring and spraying. Additionally, it is necessary to outline the specific legal regulations in Serbia that currently limit the use of drones in agriculture.

Considering the importance of agriculture in the WBC's economy and the underutilisation of innovative technologies, the aims of this paper are to (1) present the possibility of applying drone technologies in regular agriculture; (2) indicate their practical advantages compared with conventional tools; (3) highlight the legal regulation that defines the use of drones in the agricultural and food sector in Serbia and other WBC; and (4) critically review legal status and other dimensions of drone usage in the mentioned region of Europe.

2. Economic Effects of Drone Usage in Plant Protection

Recently, drones have become increasingly popular for personal and professional use in all areas of society and the economy. Their professional usage is more obvious in advanced countries, while in developing countries, the use of drones is more often present in scientific and research work. The situation is quite similar in plant protection management, where drones gain an important purpose primarily due to their ability to access hard-to-reach areas and cover large areas quickly and efficiently [15–17]. One of the main advantages of drones is their ability to access areas that may be difficult or dangerous for humans to reach. This can be particularly useful for monitoring and protecting trees in forests or orchards, as well as for monitoring crops or medicinal and aromatic plants (MAPs) in hilly or mountainous regions. In plant protection, drones can be used to collect data and monitor plant health, as well as detect and address pests and diseases. In addition to monitoring and detecting problems, drones can also be used to apply pesticides and other plant protection products, such as biocontrol agents. Using drones for this purpose can be more time efficient and environmentally friendly than traditional methods, as it reduces the amount of chemicals needed and the risk of over-application [11].

One of the main advantages of using drones for plant protection is their ability to monitor large areas in a short amount of time. Drones equipped with thermal cameras can detect temperature differences in plants, which can be an early indicator of pests or diseases. Similarly, drones equipped with hyperspectral cameras can also detect changes in the chemical composition of plants, which are most likely indicators of numerous problems such as diseases or a lack of water [18]. Drone images in combination with land data play a pivotal role in precision agriculture, offering ample opportunities for scientific research and development. These technologies provide valuable insights and enable more precise and efficient agricultural practices [18].

UAS have particularly been applied in fruit growing, viticulture, and vegetable production, where it is necessary to conduct detailed monitoring of plants and the areas of interest are significantly smaller than in crop production. This approach brought new weed control strategies, such as weed mapping, which are based on machine learning and processing large quantities of data collected by drones. With the assistance of appropriate algorithms, pixel recognition, and the adoption of semantic segmentation techniques in plant recognition and leaf classification, these strategies could be used for more precise disease and weed mapping in the future [19,20]. Using UAV-mounted sensors, farmers can timely capture remote sensing data, which is ideal for capturing a vast volume of raw data that can be used further for assessing plant conditions, including water status, biodiversity estimations, biomass estimation, and vigor assessment [21,22]. Therefore, drones provide numerous new options and possibilities for fast and easy retrieval of crop state information, which can be the foundation for the future of precise agriculture [23].

When it comes to analyzing the financial dimension of drone spraying in agriculture, two primary cases can be identified: autonomous spraying and service-based spraying. These cases represent two distinct approaches to using drones for crop spraying, each carrying specific economic implications. This analysis, based on a case study taken for Serbia, will not consider the cost of pesticides and water.

- Autonomous Drone Spraying: Autonomous spraying involves farmers owning and utilizing their own drones for crop spraying. This approach brings benefits such as reduced service costs, greater flexibility in work scheduling, and rapid response in emergencies. However, challenges include the initial costs of acquiring the drone and technical training. Additionally, maintaining the drone requires additional resources. The cost depends on the drone model used and the necessary accompanying equipment for that specific model. For the purpose of a general economic analysis, we will consider the example of the DJI Agras T30 drone, currently widely used in Serbia. Costs associated with autonomous spraying include fuel for the generator, fuel for transporting the drone (e.g., by car with a trailer) to the field, and costs allocated for drone depreciation. To charge the DJI Agras T30 drone battery during operation, an approximate 9.5 kW generator is required. In the case of a gasoline generator, fuel consumption ranges from 0.4–0.5 L/ha of treated land. According to the Price List of Machinery Services for 2023 published by the Cooperative Union of Vojvodina [24], which we will use as a reference for this analysis, the average price of 1.62 €/L of unleaded gasoline with 100 octanes. Based on this calculation, the cost of fuel consumed during battery charging while spraying ranges from €0.64–0.80 L/ha. According to current market conditions, an approximate depreciation cost of 7.5 €/ha can be considered [24]. Therefore, excluding costs of water, pesticides, drone transport, and pesticide solution to the treated field, as well as labor costs, the cost of operating the DJI Agras T30 crop spraying drone can be estimated at 8.22 $\pm$ 5% €/ha.
- Service-Based Drone Spraying: Service-based spraying involves farmers hiring professional service providers who use their drones for crop spraying. This approach eliminates initial costs of drone procurement and training, provides expertise from service providers, and allows scalability based on the treated area. However, service costs can be a significant factor, along with dependence on service availability and lack of direct control over spraying timing. The cost of annual formation of spraying services in Serbia can be compared with the Price List of Machinery Services for 2023 published by the Cooperative Union of Vojvodina [24]. A comparative price overview is presented in Table 1.

Table 1. Comparative price overview. The price does not include pesticide and water consumption, and the drone service price depends on the contracted treated area [24].

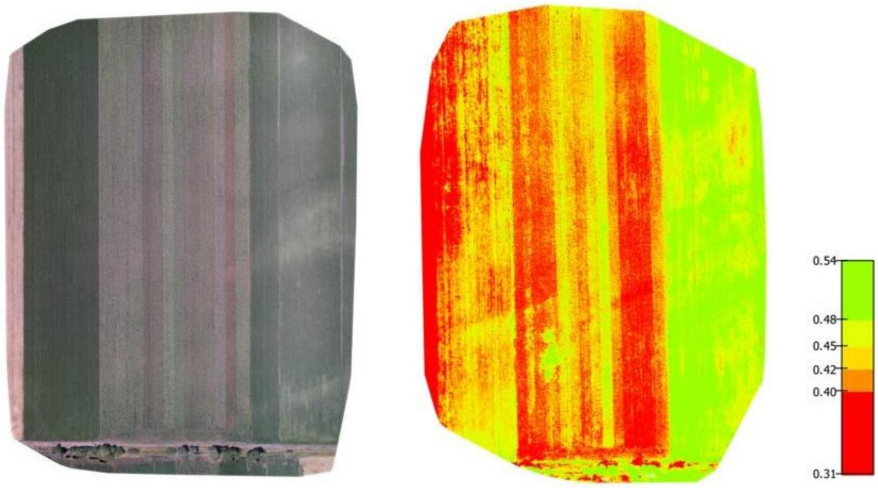
No.	Service Description	Unit	Price €/ha
1.	Tractor spraying of arable and vegetable crops without air support	ha	28.32
2.	Tractor spraying of arable and vegetable crops with air support	ha	34.12
3.	Spraying with high-clearance self-propelled sprayer	ha	37.54
4.	Drone Spraying	ha	30–45

3. Deep Technologies behind Drones' Usage

The drone control system can operate in either a semi-automatic or automatic manner. In the semi-automatic mode, a trained professional is required to input flight parameters and take control of the aircraft when encountering unsafe terrain or unexpected weather conditions, particularly during landing or obstacle avoidance. The person responsible for the creation of airborne missions can manipulate various parameters such as terrain dimensions, flight altitude, overlap between images (front lap and side lap), camera angle, and other image-related features. On the other hand, fully autonomous drones are equipped with control systems that enable them to autonomously perform predefined tasks, including flight, flight path, capturing images, and landing, without the need for operator assistance [25,26].

A crucial factor in conducting successful UAV missions and obtaining accurate data is determining the optimal combination of sensor parameters and flying height to capture images with sufficient resolution. These settings vary depending on the specific task at hand, such as plant counting, biomass estimation, detecting crop anomalies, identifying water or nutrient deficiencies, or detecting pest infestations. Higher ground resolution is typically required for capturing small objects, which can be achieved by flying at lower altitudes. However, it is important to note that flying at lower altitudes may not be suitable for all situations and issues that need to be addressed. Several factors, including vegetation height and growth, terrain complexity, and the capabilities of the sensors and drone, need to be considered when determining the appropriate flying altitude. Ensuring aircraft stability during the flight mission is crucial to preventing errors and image blurring caused by variations in brightness and image destabilization. Capturing UAV images at high speeds can lead to blurred images due to a slow shutter speed. Moreover, strong winds can significantly impact the drone's motion, resulting in unsharp images. It is important to maintain stable flight conditions to obtain clear and high-quality aerial images [27].

Acquired UAV images are further processed depending on the agricultural task that needs to be fulfilled and are often used in conjunction with machine learning techniques to solve a variety of complex agricultural problems. If the images are collected using predefined missions, they can be stitched together to generate high-resolution georeferenced orthomosaics or orthophotos from which meaningful information can be extracted (Figure 1).



(**a**) (**b**)

Figure 1. Orthomosaic of maize cultivars generated with an RGB camera (**a**); NDVI orthomosaic of the same crop with the corresponding scale (**b**).

This step additionally requires photogrammetry software and image processing skills [27,28]. Usually, these tasks are related to calculating vegetation indices, which are related to plant nutrient deficiencies, water supplies, or spotting potential diseases. The creation of orthophotos requires information regarding the sensor's location and orientation. Traditionally, this has been accomplished using expensive, high-precision global navigation satellite system (GNSS) devices in conjunction with an inertial measurement unit (IMU). However, more recently, machine vision imagery has emerged as a more cost-effective alternative for obtaining this information [29].

A UAV pilot requires relevant field experience and a comprehensive understanding of drone regulations to effectively carry out operation. This includes having proficient flying skills and maintaining composure to accurately perform the tasks at hand while ensuring the safety of others involved. Being up to date with drone regulations helps ensure compliance and promotes the safe operation of drones in accordance with legal requirements [30].

UAVs have several practical applications, including photography, videography, and delivery, and are rapidly gaining popularity [28]. Smart drones and deep machine learning deliver low-cost precision agriculture and allow sectors of UAS to scale and intensify their impact across many. For instance, with the help of UAV, any area can be represented in maps for pest and weed monitoring, vegetation mapping, irrigation, and soil erosion management. The drone-made maps help keep track of the health of plants and animals and display changes or dangers before they get out of control.

There is a wide range of very affordable drones on the market for simple and easy visual observation. For professional use, special models are provided that have cameras with a larger number of channels and complex software system for processing these recordings. Professional scanning services by certified operators are also available, which are often more affordable and simpler. Independent mapping requires complex training, passing exams, registration and insurance of the drones, an operating license, and other documents that are in accordance with laws and issued by competent state authorities [31]. On a global level, China is one of the biggest market leaders in the production and application of UAVs in precision agriculture. China's large-scale implementation of this technology reflects the country's commitment to modernizing its agricultural practices and addressing food security challenges. With this approach, UAV certainly contributes significantly to more sustainable and efficient agricultural practices [32–34]. On the other hand, Balkan countries are still adopting UAV technology in various sectors of industry, and research efforts in the agricultural sector are ongoing to improve their capabilities and applications, especially for variable spraying and environmental monitoring. Although the countries of the Western Balkans are still lagging behind, they are continuously evolving both in the application of UAS and other latest technological achievements in the field of precision agriculture.

4. Application of Chemicals

The introduction of drones in chemical or biological plant protection, soil analysis, and plant sowing is becoming rapidly popular and more ubiquitous in agricultural practice. While sensing drones could help detect pest hotspots, actuation drones could control these hotspots through the variable application of pesticides [11]. Drones have the capacity to carry reservoirs of suitable size, allowing efficient spraying of fertilizers, herbicides, or pesticides over large agricultural areas in a shorter period of time. The use of drones for crop spraying offers several advantages, including increased safety and cost effectiveness through autonomous and pre-programmed operations based on specific schedules and routes. Drones are equipped with technologies such as ultrasonic echoing, TOF lasers, and GNSS signals, enabling them to self-adjust their altitude and speed, ensuring uniform and optimal spraying results even across varying topography. In terms of efficiency, drones can significantly enhance spraying capacity, completing tasks up to five times faster than traditional machinery [26].

Drones are not the first aerial pesticide application tools used in agriculture. Aircraft have been used for decades for spraying pesticides, with major drawbacks such as product deposition over large areas and significant losses due to drift [35,36]. One of the initial developments of a UAV for pesticide application, an unmanned helicopter, took place in 1983 by Yamaha Motor Co., Ltd., located in Shizuoka, Japan. However, the helicopter's stability and controllability proved inadequate for practical use in the field. Subsequently, numerous researchers dedicated their efforts to enhancing the stability and controllability of UAVs, as well as improving their spraying systems [37]. In [38], the development of control systems and automation of drones in agriculture is presented. Today, pre-programmed and remotely controlled UAVs, adaptive approaches for pesticide spraying in dynamic environments, and algorithm-based multi-use UAV systems have been advanced.

Furthermore, specialized drones for uniform spraying have appeared; these technical developments use Raspberry Pi controllers based on artificial neural networks integrated with spraying systems. These advances have facilitated the transition from semi-controlled devices to fully automated systems that rely on an algorithmic control system for crop spraying drones. Crop spraying drones are gaining popularity in agriculture, enabling the application of pesticides and nutrients on smaller areas. On average, they can cover 10 to 20 hectares per hour, depending on the working conditions [13]. The spraying system varies by model but typically includes nozzles or centrifugal spraying system, a dosing system, reservoir, batteries, and navigation components [38].

Considering the high risk to neighboring terrestrial and aquatic ecosystems, as well as to human health, the application of pesticides by aircraft has encountered increasing obstacles in regular agricultural practice [11]. Major factors determining spray drift are droplet size, weather conditions (wind speed and direction), and application method [11]. Improved methods of pesticide application are highly needed [39], and there is potential for the use of drones in precision application of insecticides and miticides [15–17]. One of the significant advantages of utilizing UAVs for crop spraying as opposed to traditional tractor sprayers lies in their remarkable capability to navigate and operate in terrains that are typically inaccessible to conventional equipment (Figure 2). Whether it is tackling marshy or muddy areas encountered in field production after rainy days, UAVs demonstrate their versatility and adaptability [38,40]. This technological advancement opens new possibilities and addresses the limitations faced by traditional methods. Using tractor sprayers becomes a risky undertaking during critical growth stages when crops reach heights exceeding one meter. The risk of damaging the plants outweighs the benefits of pest control, especially in inclement weather conditions such as heavy rainfall. The conventional approach of using tractor sprayers or high-clearance sprayers can lead to significant economic losses due to crop and soil trampling, undermining the very purpose of spraying [40]. UAVs, on the other hand, offer a distinct advantage by minimizing crop damage and leaving no wheel tracks in their wake. This preservation of crops translates to an additional harvest yield of up to 6%, providing a substantial boost to agricultural productivity and profitability [40]. Moreover, softer soil poses yet another challenge for traditional ground-based spraying systems. Tractor wheels and high-clearance sprayers struggle to navigate such terrain effectively, hindering the application process and compromising its efficiency. In these scenarios, the utilization of UAVs emerges as a practical and efficient solution. The agility and flexibility of UAVs enable them to navigate soft soil effortlessly, ensuring that no area goes untreated and optimizing the effectiveness of crop spraying operations. This not only saves time and resources but also enhances overall productivity [38].

Figure 2. Spraying barley crops in the zone of the irrigation system, which is inaccessible to tractor sprayers.

In the application of UAVs for spraying purposes, the characteristic feature is the maintenance system of the UAV in the air through the operation of the propellers, which creates an air support for the nozzles of the spraying system. This way, the application material is blown into the plant mass [41].

This air support turns the leaves of the plants, creating the effect of applying the active substance to both the upper and lower sides of the leaf mass. It should be noted that the mass of the aircraft directly affects the strength of the air support, in such a way that an aircraft with a higher mass creates a stronger vertical air current to maintain its own flight and thus greater air support for the spraying system. This aerial support reduces the occurrence of drift, which is considered one of the biggest problems when protecting plants by spraying. The occurrence of drift in such plant protection systems attracts attention, and research is often focused on investigating parameters that influence the occurrence of drift in such systems. The use of drones in the field of crop protection is advancing rapidly, and, today, drones with spray tank capacities of 30 and 40 liters are being used, which can have a maximum take-off weight of up to 70–80 kg. The use of larger drones significantly reduces the occurrence of spray drift. The study demonstrated that higher wind speeds in the vertical direction improved spray uniformity and penetration while decreasing drift [15].

Additionally, like tractor sprayers, UAVs are equipped with GPS systems and sensors such as radars for precise navigation and controlled spraying in diverse environments. This system configuration, along with software support, enables the application of variable-rate field treatment. Variable-rate spraying is a technique used for precise or zonal spraying of crops (only in places where there is a need). This principle is based on the idea of varying the amount of treatment that is dispersed depending on various factors, such as the plant species, growth stage, weather conditions, and localized occurrence of pests. The authors of [42] showed that even though the efficiency of variable-rate spraying in cotton is lower than that of traditional boom sprayers attached to a tractor (drone efficiency: 61.3–64%; boom sprayer efficiency: 68–90% against spider mites), producers are more willing to use UAV application techniques because of their unique advantages in terms of water and medicine savings, as well as their high operating efficiency, non-rolling of cotton sticks, and no dragging of bolls during operation. The use of drones for chemical protection of plants is based on recording the surface under cultivated plants and deciding which parts of the surface should be chemically treated. After deciding, the drone can adjust its height and position according to the treated surface and spray the appropriate amount of chemicals. The main advantage of this method is that it provides effective chemical protection in real time with minimal time consumption and a reduction in the amount of chemical agents used. This strategy significantly contributes to environmental protection and especially reduces the possibility of groundwater pollution. At the same time, using drones for chemical protection purposes can save up to 90% of water, as well as 30% to 40% of pesticides [11,26]. Therefore, the small diameter of the cover contributes to better surface coverage, as well as more successful protection. On the other hand, the results obtained in the experiments conducted by [43] demonstrated that image data acquired from a UAV with a multispectral camera could be effectively utilized during the early post-emergence stage of maize. Variable-rate spraying utilization led to a reduction in herbicide usage without any adverse effects on crop yield. Additionally, it resulted in increased biomass production compared with areas that were not treated. The implementation of patch spraying, as opposed to blanket application, resulted in herbicide savings ranging from 14% to 39.2%, corresponding to savings of EUR 16 to 45 per ha [15]. It is important to note that the amount of herbicide saved is dependent on the extent of weed coverage and the level of infestation across the field.

It is very important to emphasize the fact that there is no direct human activity in the drone spraying process. Practically, the drone pilot is at a safe distance from the surface being sprayed, so the impact of pesticides on humans is significantly reduced [13]. Current research focuses on improved spray coverage to enable large-scale adoption of drones for pesticide application [11]. In combination with precision monitoring, precision application of pesticides could reduce the overall number of sprays, contributing to reduced pesticide use and decreased development of resistance, as well as an increased presence of natural enemies [44]. The adoption of drones in agriculture heralds a new era of efficiency and precision in crop protection management. By enabling targeted chemical applications, drones not only conserve resources but also minimize environmental impact and potential health hazards. As we move forward, the fusion of drone technology with agriculture promises to reshape and enhance sustainable farming practices. Nevertheless, the successful implementation of cross-cutting technologies in the WBC agri-food sector requires creating an integrated environment that builds on synergies among innovators and agri-businesses. Innovators must have direct access to farmers, universities, R and I centers, as well as market incentives to invest in the development of products that introduce digital agriculture either as their main product or as a complementary service to their existing portfolio [45].

5. Application of Biocontrol Agents

In modern agriculture, biological control of pests is attracting special attention due to the urgent need for environmental protection and healthy food production [46]. Biological control measures are also one of the most important components of integrated pest management (IPM), which is an indispensable segment of eco-friendly farming practices. Biological control, or biocontrol, is defined as a set of methods significant for pest control (insects, mites, weeds, and plant diseases) using their natural enemies. It relies on predation, parasitism, herbivory, or other natural mechanisms, but also involves an active human influence [47]. Living organisms used in biological control are insects, entomopathogenic nematodes, fungi, bacteria, viruses, and many others. There are currently a wide variety of commercially available natural enemies of agricultural pests on the market [11]. In a strict ecological sense, applied biological control can be considered a strategy to restore functional biodiversity in agroecosystems by adding missing entomophagous insects through classical and/or augmentative biocontrol techniques [48,49]. Using drones, especially for augmentative biological control, relies on the large-scale release of natural enemies for immediate control of pests [50]. They could distribute the natural enemies in the exact locations where they are needed, which may increase biocontrol agent efficacy and reduce distribution costs. Some minute-size natural enemies, such as insect-killing fungi and nematodes, can be easily applied with conventional spray application equipment [51,52].

Biocontrol is considered more sustainable than other pest management strategies primarily because of the agents' ability to establish persistent and self-dispersing populations at the landscape scale [53]. Releases in strategically chosen locations can facilitate agent dispersal and achieve widespread establishment [54,55] by overcoming the limited dispersal ability of an agent [53] or a fragmented distribution of the target pest [55,56]. However, it is not always possible to access these infestations or efficiently release agents within them [57]. Traditional operational methods often do not integrate well with biological control strategies. This is primarily reflected in the difficulty of applying biocontrol agents in full vegetation or accessing inaccessible or wet terrain in the right time frame. Drones may help solve these logistical challenges and overcome the dispersal limitations of agents [57]. The introduction of drones into agricultural practice can contribute to solving these field challenges, facilitate the application of bioagents, and accelerate their establishment in the targeted crop. While most drones used in invasion biology and management focus on applying drone imaging capabilities to monitor invasive plant species [58], researchers have recently begun to use drones to release biological control agents [59,60].

According to [57], there are several advantages to using drones in biocontrol:

- Precision: Drones can be programmed to follow precise flight paths and apply biocontrol agents only to specific areas, reducing the risk of overspray or off-target application;
- Efficiency: Drones can cover large areas quickly and can be used to apply biocontrol agents at specific times or stages of pest development to maximize their effectiveness;

- Safety: Drones can reduce the need for people to work in potentially hazardous environments, such as areas with high levels of pesticides or areas with dangerous pests, such as venomous spiders;
- Sustainability: The use of biocontrol agents can reduce the need for chemical pesticides, which can have negative impacts on the environment and human health;
- User friendliness and technical aspects: Simple operation, low operating cost, high operating efficiency, and wide application range [46].

Extreme weather conditions significantly limit the use of drones for applying biological or chemical agents. The impact of heavy rains and high winds on UAV field performance is likely to cause numerous problems, such as drift and uncontrolled deposition. Unfavorable meteorological conditions above all prevent the proper distribution of the applied agent, but these conditions are a limiting factor for all other methods and tools of applying plant protection agents [61].

The authors of [11] stated that various ground mechanical distribution systems have been developed to facilitate predator dispersal, such as the Mini-Airbug, a hand-held appliance with a fan, as well as many other devices [62,63], but adoption has not been widespread. Although the release of natural enemies by aircraft was proposed in the 1980s [64], real progress was made after the introduction of small drones into agricultural practice. In practice, small drones have shown numerous advantages over manual or aircraft distribution by reducing application costs and covering larger areas, significantly increasing the use of natural enemies in favor of pesticide sprays. The development of drone-mounted dispensers has mainly focused on two types of natural enemies: predatory mites and parasitoid wasps [11].

The production, distribution, and application of beneficial organisms via drones has quickly become global, and various types of bio-agents specific to certain crops and pests are now being applied worldwide. For control of the two-spotted spider mite *Tetranychus urticae* Koch, 1836 (Trombidiformes: Tetranychidae), an important pest of many crops worldwide, a California-based company called Parabug offers services to distribute predatory mites using drones on crops such as strawberries [11]. The University of California has developed a platform for drone-based distribution of predatory mites called BugBot. They developed the prototype and accompanying software to optimize the release of beneficial organisms [11]. A similar trend is present in Australia, where commercial companies and academic institutions use drone-mounted devices developed to distribute predatory mites in corn and strawberry crops [65]. In addition to predatory mites, parasitoid wasps such as *Trichogramma* spp. Westwood (Hymenoptera: Trichogrammatidae) are important biocontrol agents of the European corn borer (ECB) *Ostrinia nubilalis* Hübner, 1796 (Lepidoptera: Pyralidae) [66]. These wasps are the most popular biocontrol agents worldwide. Various companies and research institutes around the world have started *Trichogramma* drone applications (Figure 3), including Austria, Germany, France, Italy, and Canada [67]. Drone-released *Trichogramma* parasitoids are also deployed in China for the control of pests in sugarcane [68]. In Brazil, drone applications of *Trichogramma* spp., as well as the parasitoid *Cotesia flavipes* Cameron, 1891 (Hymenoptera: Braconidae), are used to control the sugarcane borer *Diatraea saccharalis* Fabricius, 1794 (Lepidoptera: Crambidae) [11]. *Trichogramma* spp. are also employed against various lepidopteran pests in other crops [69]. The use of *Trichogramma* wasps in biological control is common worldwide, but its potential has not been explored for many pests and in many geographic regions. Serbia is one of the countries at the southeast border of Europe that does not currently use *Trichogramma* in its agricultural systems [70]. However, monitoring of ECB on the territory of Serbia since 2010 has shown the presence of *Trichogramma* parasitized egg clusters and significant rates of parasitism, which can be used to both justify and direct the rearing and release of *Trichogramma* in Serbia [70–72]. Parasitoid wasps are not the only native species of beneficial insects registered on the territory of Serbia. Recently, representatives of the genus *Trissolcus* (Hymenoptera: Selionidae) have been registered at several different locations in Vojvodina Province, northern part of Serbia [73]. These insects are widely distributed in biocontrol and are suitable for application by UAS, which makes them good candidates for commercial introduction into Serbian agriculture. One of the main limiting factors for the successful application of the above-mentioned bioagents in WBC's agriculture is the lack of national strategies or action plans for their commercialization, as well as available tools for their effective field application. In this context, any promotion of drone-based strategies in the entire Western Balkan region is more than justified in order to accelerate the introduction of biocontrol measures in regular agriculture practice. Additionally, the competitive market price of chemical agents in the Western Balkans significantly limits the transition from chemical to biological protection. In such market conditions, farmers strive for more cost-effective production and higher profits, so they often go for less expensive products. In Western Europe and the United States, biocontrol agents have become competitive with chemical crop protection, primarily due to growing environmental awareness among farmers, but also due to numerous domestic producers of beneficial organisms, which reduces the market price of biocontrol products. In this sense, the long-term national strategy for the utilization of biocontrol measures in WBC's agricultural and forestry sectors should include the education of farmers about the impact of the chemicals on food safety, as well as the financial stimulation of domestic companies for the production and mass rearing of beneficial insects. Such a strategy would significantly reduce the market price of biocontrol agents and make them more competitive compared with chemical protection.

Figure 3. Drone DJI Matrice 100 for Trichogramma application (taken from https://www.drone-store.it/; accessed on 1 July 2023).

According to [46], other types of natural enemies can also be drone applied, such as the green lacewing, *Chrysoperla* spp. Steinmann, 1964 (Neuroptera: Chrysopidae), or the minute pirate bug, *Orius insidiosus* Say, 1832 (Hemiptera: Anthocoridae), to control aphids and thrips, and the mealybug destroyer, *Cryptolaemus montrouzieri* Mulsant, 1850 (Coleoptera: Coccinellidae), to control mealybugs. The same researchers from the University of Southern Denmark are currently developing a dispensing mechanism for ladybirds (Coleoptera: Coccinellidae) and other important natural enemies of aphids. However, there is always plenty of space for improvement of existing drone-based dispensers or development of new solutions for the distribution of many other types of beneficial organisms as well. There are also some challenges and limitations to using drones for biocontrol, including legislation issues, the cost of acquiring and maintaining the technology, and the need for skilled drone operators [11]. In the WB countries, the applicability of biological control measures is still at a very low level, primarily due to the long tradition of chemical crop protection among producers. A factor that additionally limits the usage of biological agents is certainly the lack of solutions for their application. The above-mentioned examples of good biocontrol practices clearly guide agriculture towards a successful transition to innovative techniques and eco-friendly solutions in the field of modern plant protection. Biological control and the usage of beneficial organisms, including insects, is still in the experimental phase in WB countries. By far, Serbia and Croatia have the most dedicated experimental initiatives around biological control, especially in terms of determining the natural potential of beneficial organisms [70–74].

6. Legislation for the Use of Drones in Agriculture: A Case Study in Serbia

Despite their many potential uses, drones have also raised concerns about privacy and safety. There have been instances of drones being used to invade privacy by spying on individuals, and there are also concerns about the potential for drones to cause accidents or be used for nefarious purposes, such as smuggling contraband into prisons or causing damage to critical infrastructure [31]. To address these concerns, governments around the world have put in place regulations to govern the use of drones. These regulations may include requirements for pilot licensing, limits on the altitude and distance that drones can fly, and restrictions on the use of drones in certain areas, such as near airports or over crowds.

The Civil Aviation Directorate (CAD) is responsible for drafting, amending, and supplementing regulations in the Republic of Serbia [75]. The Directorate adopted a new regulation that entered into force on 15 February 2020.

The Regulation on Unmanned Aircraft in Serbia is not applicable to unmanned aircraft with a maximum take-off mass of less than 0.25 kg and a maximum speed of 19 m/s while reaching a maximum kinetic energy of 80 J or unmanned aircraft with a maximum take-off mass of over 150 kg [76].

Based on Article 4 of the Regulation on Unmanned Aircraft [76], all unmanned aircraft that belong to Categories 3 and 4 must be entered onto the aircraft register maintained by the Civil Aviation Directorate of the Republic of Serbia. Furthermore, unmanned aircraft from Categories 1 or 2 must be entered in this register if they are flying under the following conditions:

- At an altitude above 100 m.
- Near airports.
- Over or in the vicinity of people (less than 30 m).
- At a horizontal distance greater than 500 m from an unmanned aircraft operator.
- Within a restricted area.
- At night.
- Releasing fluid or objects or carrying external cargo is not an element of the structure of an unmanned aircraft.

The majority of agricultural production occurs in unpopulated areas. The portion of airspace above this land usually belongs to unmanned aircraft flight regions I and II. The first region is located above an “undeveloped and uninhabited area where there are no persons other than the person operating the unmanned aircraft”, while the second region is located above a “constructed or uninhabited area where there are buildings not intended for human habitation, with a possibility of retaining people for a short period of time”. There are two more unmanned aircraft flight regions. Region III is space above a residential area, and region IV is space above a densely populated area. According to Article 14 [76], only unmanned aircraft that belong to Category 4 must obtain approval by the Directorate to be operated in regions I and II.

While operating Categories 2 to 4 of unmanned aircraft, the operator is obliged to have certain documents with them, as follows:

- A certificate for passing the knowledge test that is conducted by the Directorate, with at least 75% of the questions answered correctly;
- The manufacturer’s instruction manual for the particular aircraft, in paper or electronic form;
- Document proving the operator’s medical fitness;

- Approval of the Directorate for Categories 3 and 4, and special cases described in the text above for Categories 1 and 2.

For operating unmanned aircraft that belong to Category 1, the operator needs these papers only in cases where the flight must be reported and registered by the Directorate; in other cases, the operator of Category 1 unmanned aircraft is not obligated to pass the test or have the rest of these papers.

According to Article 5 [76], for entering the unmanned aircraft in the register, the following documents are required:

- Proof of customs duties paid if the aircraft was manufactured in a foreign state, or a certified written statement of the owner if the aircraft was manufactured in the Republic of Serbia;
- The manufacturer's instruction manual for the use of the unmanned aircraft, in Serbian or English;
- Liability insurance contract for damage to third parties.

Even when they fulfill their obligations enacted by the Regulation on Unmanned Aircraft, Serbian farmers still have certain legal issues that follow pesticide application by unmanned aircraft. The Serbian Law on Plant Protection Products has certain restrictions for this type of application [77]. According to Article 48 [77], the application of plant protection products from aircraft is only permitted for those for which it was determined during the registration procedure that they may be applied from aircraft and if the registration decision allows for this method of application. In Article 20, paragraph 2, point 1 of this law [77], the decision on registration must provide information about the possibility of pesticide application via unmanned aircraft. At present, there are no such officially registered pesticides, or at least none that have this information on their labels.

In Article 45, paragraph 1, point 6 [77], it is written that the application of plant protection products poisonous to bees from aircraft is prohibited. Notwithstanding this point, plant protection products that are not safe for bees may be applied only in the event of the suppression of harmful organisms from the lists prescribed by the government or for treating the plants, plant products, and prescribed objects from the lists. According to Article 49 of the Law on Plant Protection Products [77], which also refers to plant protection products that are poisonous to bees, these pesticides may be applied under the following conditions:

1. The person applying plant protection products must notify the local beekeepers, their association, and the local self-government authorities about the impending application of plant protection products at least 48 h before the treatment, indicating the application method, in order to take the relevant protection measures.
2. Bee societies should be located at least five kilometers away from the treatment site. The lack of clear instructions on pesticide labels indicating whether it is suitable for application from a drone complicates the process of choosing the right pesticide, particularly insecticide, for farmers and makes the entire process of treating plants with unmanned aircraft much more difficult than it needs to be. Most herbicides, fungicides, and miticides are relatively nontoxic to honeybees and can generally be used safely around them [78]. However, certain herbicides, such as glyphosate, can have an impact on bee navigation, learning, and larval development [79]. To avoid the unintentional use of toxic substances, all licit pesticides that are non-poisonous to bees should be labeled for safe application via drones.

7. Other WBC and Their Regulations on Drone Applications

In other countries of Western Balkans, Macedonian Civil Aviation Agency (MCAA), Montenegro Civil Aviation Authority (CAA), the Albanian Civil Aviation Authority (AAC), and Bosnia and Herzegovina's Directorate of Civil Aviation (BHDCA) are responsible for drafting, amending, and supplementing regulations relating to the use of unmanned aerial vehicles [80]. The national agencies listed above are responsible for drone safety and have provided several internet-accessible details on flying for fun or work [80]. An important role in defining the rules and recommendations for flying drones in the countries of the Western Balkans is played by the International Civil Aviation Organization (ICAO), a United Nations agency established to help countries share their skies for mutual benefit. The ICAO developed the ICAO UAS Toolkit, a helpful tool to assist countries in realizing effective UAS operational guidance and safe domestic operations. ICAO UAS Toolkit presents UAS best practices, lessons learned, and regulations for consideration in order to help countries benefit and prosper from their improved compliance with global norms [81]. Unlike the CAD, MCAA, CAA, and BHDC which have explicit drone use regulations, the Albanian Civil Aviation Authority has not codified regulations on the use of drones in Albania. According to AAC, drone operations are not adequately adjusted in Albania in the absence of explicit regulations. Therefore, for the safe use of drones in Albania, it is necessary to contact the AAC and follow the recommendations of the International Civil Aviation Organization [80]. Although the general rules for the use of UAVs are fairly uniform among the countries of the Western Balkans and are mostly compliant with ICAO recommendations, there are still certain specificities. The most obvious distinction is the categorization of drones according to their maximum take-off weight (Table 2). Bearing in mind these differences, which can represent a limiting factor, especially from the aspect of international cooperation and integration of the WB countries with the rest of the EU regulations [82], it is crucial to revise and harmonize the existing rules and recommendations in order to create a safe environment for the maximum use of drones both in agriculture and in other economic areas.

Table 2. The classification of UAV by maximum take-off weight per WB countries in comparison to EU regulations [80,82].

Drone Categories	Serbia	Republic of North Macedonia	Montenegro	Bosnia and Herzegovina	EU Regulations
1	0.25–0.9 kg	<0.5 kg	<5 kg	249 g–1 kg	<250 g
2	0.9–4 kg	0.5–5 kg	5–10 kg	1–2 kg	250–900 g
3	4–25 kg	5–20 kg	10–20 kg	2–5 kg	900 g–4 kg
4	25–150 kg	20–150 kg	-	5–25 kg	4–25 kg
5	-	>150 kg	-	-	>25 kg

8. Participation of WB Countries in EU-Supported Projects Covering State-of-the-Art UAV and Related Technologies: Case Studies

Although legislation of mentioned WB countries is not fully in accordance with EU legislation and has certain limitations (especially non-EU member states of Western Balkans), all of them are actively participating in large-scale EU-funded projects which are dealing with UAV and related technologies. For now, limiting legislation is not stopping major research institutes from delivering precision agriculture experiments and contributing to scientific knowledge on using various robotics solutions in agriculture and food industries (Table 3). Some of them, such as the BioSense institute from Serbia, are becoming experienced project leaders of Horizon 2020 projects dealing with various pilot solutions in UAV crop monitoring and using machine learning/AI in digitizing agriculture. For example, AgroRoboFood project of the mentioned institute was the first of its kind to incorporate a re-granting scheme for additional support of small pilot experiments dealing with the innovative design of manned and unmanned aircrafts and terrestrial robotic solutions in agriculture. Unfortunately, even nowadays, none of the projects tackled advocacy initiatives nor any related actions which can improve the legislative framework and enable a more open environment for the wider usage of drones and related technologies in the agrifood sector. This is obviously a work in progress for the WB countries, especially in terms of the EU accession process as well.

Table 3. State-of-the-art case studies science-based projects promoting UAV/drone-related technologies in agriculture and biological sciences. These are the projects supported by either HORIZON2020 or COST Action EU programs. All or some of the WB countries are participating mostly as partnering countries (Serbia, Croatia, Bosnia and Herzegovina, Montenegro, North Macedonia, Slovenia). Project participant lists are available in the links within the table.

	Project Acronym	Supporting EU Programme	Full Title of the Project (If Available)	Scientific Field	Technologies Incorporated	* End Year of Project	References
1	AgroRoboFood	Horizon 2020 project (GA 825395)	Business-Oriented Support to the European Robotics and Agri-food Sector, towards a network of Digital Innovation Hubs in Robotics	Agriculture, Food Industry	Robotics, UAV, and others	2023	[83]
2	DEMETER	Horizon 2020 project (857202)	Building an Interoperable, Data-Driven, Innovative, and Sustainable European Agri-Food Sector	Agriculture, Food Industry	Precision farming, UAV-driven monitoring, and others	2023	[84]
3	SmartAgriHubs	Horizon 2020 project (818182)	Connecting the dots to unleash the innovation potential for digital transformation of the European agri-food sector	Agriculture, Food Industry	Digital innovations, precision agriculture, and others	2022	[85]
4	Robs4Crops	Horizon 2020 project (101016807)	Robots for protecting crops	Crop Science, Agriculture, Food Industry	AI, robots, UAV, precision agriculture, and others	2024	[86]
5	SENSECO	COST Action (CA17134)	Optical synergies for spatiotemporal SENsing of Scalable ECOphysiological traits	Ecophysiology, Biology	Robotics, satellite imaging, optical measurement, and others	2023	[87]
6	InsectAI	COST Action (CA22129)	Using Image-Based AI for Insect Monitoring and Conservation	Entomology, Pest Monitoring	AI, computer vision, robotics, and others	2027	[88]

* Although the official end year of the project is put in the table, most of the projects are still currently running, in changed or unchanged form/scope, taking into account the fact that EU-funded projects need to have sustainability strategy and project life cycle run even after the official ending of the funding (more on sustainability strategies: [89,90].

9. Discussion

Throughout history, agricultural production has undergone several major changes, most of which were the result of technological progress. Today, information technologies are at the forefront of innovative breakthroughs in the agri-food sector [13]. Drones, as a product of technological progress, are powerful tools that, in combination with information technologies, have found multiple uses in various spheres of society and the economy. Using drones for plant protection can be a highly effective and efficient method for farmers and other agricultural professionals to monitor and manage their crops. Drones equipped with sensors, cameras, and other technologies can provide real-time data on plant health, moisture levels, and other environmental factors, allowing farmers to make informed decisions about when and where to apply pesticides, herbicides, or other treatments. In developed countries, drone-based technology is significantly improving the agri-food sector and transforming agriculture into a high-tech, advanced field of industry. The use of drones and data analysis has great potential to provide support in solving some of the most important problems in the field of agriculture. By using drone monitoring techniques, the collected data are instantly processed, enabling active processing, and real-time decision making. Currently, the practical application of drones is expanding significantly faster than most industries. There are numerous reports that highlight the successful use of drones in agriculture, both for the application of pesticides and for the introduction of natural enemies [15–17,57,67,68]. Large investments as well as legislation regulating the use of drones affect the speed of development of these aircraft systems and their use in the field of agricultural production.

Nevertheless, while the use of drones for plant protection has many advantages, it is important to consider the potential risks, negative impacts, and its disadvantages. The (UAV) market is constantly changing and nowadays technological improvements have shifted the use from fixed-wing drones and helicopters towards small drones based on multi-copters that cover almost 50% of the current available UAV models [38]. Every type of UAVs has their own performance disadvantages such as high operation or maintenance cost, limited flying range, time and payload weight capabilities, but with accelerated technological development and innovations with the drone embedded systems and motors most of these problems will be overcome in the near future [91]. Regarding the use of pesticides and other chemicals, these risks must be carefully regulated to ensure that they are applied safely and do not have negative impacts on the environment or human health. In that context, the application of such systems requires a skilled and trained flight and operation controller. Knowledge and training in the fields of aviation traffic and UAV management are necessary, no matter the country. In addition, there are regulatory and safety issues to consider, including the need for pilots to be properly licensed and trained and the risk of collisions with other aircraft or obstacles. It should be noted that when using pesticides for any purpose, a highly toxic substance is applied, which is dangerous both for the environment and for the health of the operator who performs the application. For this reason, it is necessary to fully comply with regulations and laws on plant protection in order to avoid unwanted circumstances. However, the fact that the operator can be up to 1 km away from the working area of the UAS certainly favors the use of drones. There are also some challenges associated with the use of drones for plant protection. For example, drones may not be able to operate effectively in adverse weather conditions, and they may be limited in their ability to penetrate thick vegetation. With the general increase in drone application in various areas of the economy and their technological advancement, it is likely that most of the current problems will be effectively overcome to enable a more diverse and efficient application of drones in the agri-food sector.

Legislation in many WB countries is based on regulations that do not recognize new systems and modern technologies, such as drones. In such a case, the regulations defining air traffic also apply to drones due to terminological deficiencies. In the case of legislation that regulates the use of unmanned aircraft, in Western Balkans, there is an evident shift towards creating weaker restrictions in order to make the use of these aircraft simpler and more applicable. In this regard, although the laws of individual countries very often represent a limiting factor for the use of drones in the agricultural sector, amended and updated legislation in accordance with technological progress is still a necessary control factor in order to use drones rationally and safely in agriculture and in other production sectors. However, it is important to carefully consider the potential risks and negative impacts and to put in place appropriate regulations to ensure that the use of drones for plant protection is safe and sustainable. Indeed, drones have the potential to revolutionize a wide range of industries and have many practical applications. It is important to carefully consider the potential risks and consequences of their use and to put in place appropriate regulations to ensure the safety and privacy of individuals.

10. Conclusions

Overall, while there are both benefits and challenges to using drones for plant protection, the technology has the potential to transform the way we approach agriculture and plant protection management. The development of drone ecosystems supported by a competitive industry will strongly support Europe's twin transition to the green and digital economy and to the future development of digitalization promoted by the European Green Deal. This is in line with "A Drone Strategy 2.0 for a Smart and Sustainable Unmanned Aircraft Ecosystem in Europe" adopted in 2022 by the European Commission. Currently, conventional agriculture is still significantly more prevalent and profitable in Serbia, but as drone technology continues to advance and become more reliable and efficient, there is no doubt that the education of agricultural producers and future investments in precision agriculture will most likely increase the use of state-of-the-art technologies and drones in modern agriculture.

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