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Comparative evaluation of current regulations regarding agricultural unmanned aerial vehicles used for spraying purposes in Türkiye

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Abstract: Pesticides have historically been viewed as dangerous because of their effects on the environment and human health. But they have also been recognised as saviours of farmers' incomes and global food security. There is no doubt a major shift in the global use of pesticides. The disadvantages of manual spraying of pesticides include low efficiency and high labour intensity. Agricultural UAV applications, which contribute positively to agriculture in terms of efficiency, economy and safety, are gaining more importance. This study, which summarises the applications of agricultural UAVs in Türkiye and around the world, discusses the legal constraints that farmers will face when using UAVs in agriculture, as well as the contributions of this technology to agriculture. Beginning with the current state of UAV use in agriculture, the international legislation and Turkish legislation were compared, and an overview of the current and future role of UAV use in agriculture was provided.

Keywords: agricultural unmanned aerial vehicle; aviation; aerial spraying; UAV legislation; Türkiye.

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1 Introduction

Agricultural production addresses the challenge of meeting the growing demand for food and raw materials by the world's population. The world population is expected to reach nearly 10 billion by 2050, resulting in a 70% increase in food production (Hunter et al., 2017). However, as the climate continues to change, pest flare-ups in agricultural fields

are becoming more common, posing new threats to crop production (Yuan et al., 2017; Lan and Chen, 2018).

With the increase in labour migration from rural to urban areas and the ageing population, new pesticide application equipment that can acclimate to small cropping areas in a mountain and hilly areas is considered necessary (Wang et al., 2016). Spraying mechanisation is becoming increasingly essential to minimise human and environmental damage while also dealing with labour shortages. Aerial agricultural spraying, both manned and unmanned, is frequently the most cost-effective and time-efficient method of ensuring efficient and effective crop pest control practices, while also allowing for rapid response to unexpected pest outbreaks (Lan and Chen, 2018). Pesticide application by unmanned aerial vehicles (UAVs) has grown rapidly in China and other Asian countries in the past few years, owing to their applicability for complex terrain, high working efficiency, lower spray volume, lower labour intensity, and lower risk of pesticide contamination to operators compared to other methods of application (Huang et al., 2009; Xinyu et al., 2014; Zhang et al., 2014).

The use of UAVs in agriculture has risen dramatically in recent years. According to the United Nations Food and Agriculture Organization, “the applications of UAVs are confined only by our imagination” (Giacomo and David, 2018). Likewise, the European Commission predicts that ‘agriculture’ will be one of the primary sectors of industries to benefit immensely from UAV technology soon (Van de Velde and Kretz, 2021).

The global drone market is valued at \$24.72 billion in 2020 and is estimated to reach \$70.91 billion by 2030 (AMR, 2022). The Association for Unmanned Vehicle Systems International (AUVSI), based in the USA, anticipates that agriculture will account for 80% of the future UAV market (Jenkins and Vasigh, 2013).

Consequently, while UAVs witnessed increased use in a variety of professional fields, the technology is particularly suited to the agricultural sector, considering legal restrictions on UAV use over densely populated urban areas (Klauser and Pauschinger, 2021).

UAVs are frequently attributed to smart or precision agriculture. Precision agriculture is a managerial strategy that relies on data from multiple sources to help farmers make better decisions (Candiago et al., 2015). Precision agriculture’s main goal is to tailor management strategies to the crop requirements, taking into account spatial and temporal information about the crop, land, and environment (Mesas-Carrascosa et al., 2015; Gonzalez et al., 2018). Farmers boost agricultural output by increasing yields while reducing inputs and extraneous environmental impacts by using precision agriculture technologies (Tey and Brindal, 2012; Pierpaoli et al., 2013). Thereby, the application of precision agriculture technologies could contribute to farmer welfare by improving farmers’ financial status, which is also critical for rural life (Morris et al., 2017).

As a result, precision agriculture technologies contribute not only to environmental protection and food supply security but also to the preservation of sustainable rural areas. The effective implementation of precision agriculture technologies is dependent on data collection (Morris et al., 2017; Gonzalez et al., 2018). Remote sensing is a high-tech method of gathering data by sensing, recording, and processing energy reflected or emitted by surfaces (Usha and Singh, 2013). Remote sensing employs the use of aeroplanes or satellites to collect data that can improve the application of precision agriculture technologies due to increased information accuracy. Clouds and atmospheric conditions, on the other hand, have an impact on satellite and aircraft visual images. Satellites are also inflexible as they cannot be quickly and easily mobilised when

appropriate (Stehr, 2015; Gonzalez et al., 2018). UAVs, as a new remote sensing application tool, transcend these drawbacks (Comba et al., 2018; Gonzalez et al., 2018).

UAVs, as opposed to satellites or manned aircraft, are less expensive, have greater functionality, are less obstructed by cloud cover, and, most importantly, provide better spatial and spectral resolution (Candiago et al., 2015; Stehr, 2015; Tripicchio et al., 2015; Gonzalez et al., 2018). UAV-captured spectral images (multispectral, hyperspectral, and thermal) can be used to monitor crop health in a variety of ways, including drought and water stress, nutrient deficiency, and the presence of pests, weeds, and diseases (Candiago et al., 2015; Moskvitch, 2015; Bogue, 2017; Hunt and Daughtry, 2018). Pesticide use, on the other hand, is an essential component of modern agriculture, contributing to the productivity and quality of the majority of agricultural products (Hilz and Vermeer, 2013). It is estimated that the use of agrochemicals prevents up to 45% of the world's food supply from being lost (Oerke, 2006).

Moreover, UAVs can help to efficiently minimise pesticide risks to people and environmental pollution during the pesticide application procedure (Wang et al., 2017). As a result, in recent years, researchers have begun to pay closer attention to the widespread adoption of UAVs in pesticide applications (Chen et al., 2020; Xinyu et al., 2014). Aerial pesticide application is not new, but sprinkler UAVs are becoming more suited to agricultural applications, both spatially (because they take flight lower than aircraft) and legally (due to simplified regulatory procedures). Spraying UAVs, on the other hand, are less expensive and technically simpler to use than helicopters.

Aerial spraying with UAVs in Türkiye requires permission from the relevant ministerial units as well as a flight operation permit to be issued by the local aviation authority. In addition, save for the established rules, aerial spraying with UAVs is prohibited. The illegal and potential use of UAVs has increased in recent years, necessitating additional regulations and restrictions (Watkins et al., 2020). UAVs are new airspace instruments that may endanger other users of the airspace (planes, helicopters, airfields, and so on) as well as third parties on the ground (Stöcker et al., 2017). As a result, because uncontrolled UAV flights endanger air navigation and transportation, an increasing number of countries are enacting regulations to mitigate the risk. As of February 2019, 44% of countries had no regulatory framework for UAVs. UAV operations are prohibited on the territory of 12 countries (6%). Nonetheless, approximately 97 countries (50%) have already established regulatory guidelines (Singh et al., 2019).

Since 2009, the European Union (EU) has outlawed all aerial spraying, primarily due to environmental concerns (Zwetsloot et al., 2018), whereas aerial spraying is legal in the USA (Reger et al., 2018). However, Switzerland has taken a more liberal stance, primarily aiming to restrict the use of helicopters to the spraying of particular fields and crops (Bauernzeitung, 2014). Regarding this, Switzerland became the first nation in Europe to approve the use of sprayer UAVs in 2019 (Agroscope Institute, 2019). In contrast to helicopters, the relevant regulatory framework in Switzerland treats sprayer drones the same as ground-based equipment for applying pesticides. The primary argument is that UAVs generate less spray drift than helicopters (Klauser and Pauschinger, 2021).

A lot of other nations with established UAV policies are constantly making adjustments to the current framework to make it more user-friendly. One of them, Türkiye, revised its regulatory framework for the fourth time in 2020 after it was first published in 2016. A few changes are anticipated to be made with the new instruction,

which is anticipated to be revised for the fifth time this year. One of them is the reduction from 500 grams to 250 grams of the maximum take-off weight (MTOW) of UAVs that must be registered.

The paper will compare international regulations with Türkiye UAV regulations based on the current state of the use of UAVs for agricultural purposes and will provide an overview of the current and potential future use of agricultural UAVs. The article is structured as follows with this in mind. Section 2 goes into detail about UAVs used in agriculture. Section 3 will scrutinise the national and local laws governing the use of UAVs in agriculture, and the final section will discuss Türkiye's differences and similarities with other nations.

2 Use of agricultural UAVs in agriculture

UAVs are characterised as future systems that are controlled and commandeered by a ground control station but do not have a pilot on board (Savas, 2022). UAVs are frequently used for civilian purposes now, despite their initial use in the military, especially in recent years (Keane and Carr, 2013). UAVs come in a wide range of designs, dimensions, payloads, and configurations, including fixed-wing and single- and multi-rotor aircraft. Electricity or fuel can be used to power UAV power systems. Most common UAVs with electrical power can fly for 10 to 45 minutes, while those with fuel power can do so for 1 to 4 hours. The majority of multi-rotor UAVs in use today are powered by electricity. This type of UAV has a straightforward structure, is simple to maintain, and has superb flight stability and spraying efficiency (Stöcker et al., 2017). Aerial spraying and other similar flight operations typically require agricultural UAVs to operate under special rules and regulations and weigh more than 25 kg.

Figure 1 Yamaha rmax agricultural UAV (see online version for colours)



Source: Yamaha (2022)

The use of agricultural UAVs has a varied history depending on the country. The birthplace of commercial UAV use in agriculture can be attributed to Japan, where the technology has been in use since the late 1970s. Yamaha developed the first agricultural drone model (Mogili and Deepak, 2018). Yamaha introduced the Model RMAX, an unmanned medium-sized helicopter with a 5 kg payload capacity, as the first agricultural UAV in 1985 (Figure 1). To spray crop fields, the company has also developed a variety

of other unmanned helicopters (KG-135, YH300, AYH3, etc.). Many countries all over the world have also started using Yamaha helicopters as research platforms. However, to preserve their technology, Yamaha helicopter exports were prohibited in 2007 (Chen et al., 2021).

Helicopters are no longer the most popular UAV platform for agricultural applications; instead, multi-rotor UAVs have taken their place. These multi-rotor UAVs can be supported by UAVs that are used for plant monitoring and can carry out heterogeneous spraying. They have different tank reservoirs, including 8, 10, 20, and 30 L. In other words, multispectral UAVs are used to map the area to be sprayed before spraying more or fewer pesticides as needed. Figure 2 depicts the agricultural UAV model Agras T30, which can spray 40 acres per hour and has a 30 L reservoir, as well as the UAV model Phantom 4 Multispectral, which has a multispectral camera, manufactured by DJI.

Figure 2 (a) DJI Agras T30 agricultural UAV (b) DJI phantom 4 multispectral UAV (see online version for colours)



Source: DJI (2022)

The potential to enhance crop yields through the use of UAVs in agricultural production is high due to the scarcity of accessible land and the ubiquitous use of manual labour in agriculture. Therefore, fertilisation, seeding, and pesticide application are currently the primary uses of UAVs. As a result of these issues, UAV technology has approximately 70% recognition and use in Japan. In contrast, in the technologically advanced the USA, this rate is about 40% (Scherer et al., 2017).

Agricultural UAVs have been capable of substituting the place of satellites, manned aircraft, ground equipment, and human labour. Agricultural UAVs improve land use while reducing inputs like labour, water, and agrochemicals to increase the efficiency of agricultural productivity. Imaging with agricultural UAVs can capture higher-resolution images with fewer air obstructions and is relatively less expensive than using satellites or manned aircraft for areas smaller than 20 hectares. The advantages of agricultural UAVs, on the other hand, can be summed up as follows (Scherer et al., 2017; Wang et al., 2019):

- It saves up to 90% of the water used in agricultural UAV spraying.
- Using agricultural UAVs to spray crops saves between 30% and 50% of chemical pesticides.

- Agricultural UAV pilots are exposed to lesser chemicals.
- It is projected that agricultural UAVs will increase productivity up to five times more than tractor-applied pesticides.
- Agricultural UAVs outperform backpack sprayers by a factor of 20.

2.1 Aerial use of the agricultural UAVs for pest control

Pesticides have traditionally been regarded as dangerous due to their effects on the environment and human health. However, they have also been identified as potential saviours of farmer income and global food security. There has undoubtedly been a significant shift in the global use of pesticides. This is especially evident in China, which has recently emerged as a major producer and exporter of pesticides. The country, which needs to feed more than 20% of the world's population but only 10% of the world's arable land, relies heavily on pesticides to boost agricultural output (Liu and Guo, 2019). As a result, pesticide overuse is a major issue, particularly in China (Gong et al., 2016). In 2016, farmers in China used approximately 1.8 million tons of pesticides, the majority of which were applied manually (Matthews, 2019).

The disadvantages of manual pesticide spraying include low efficiency and a high labour strength. Manual spraying wastes resources and has other negative consequences such as excessive pesticide residues, pollution, and a higher risk of pesticide contamination for farmers who employ it (Fan et al., 2013). Pesticide poisoning is estimated to impact over 50,000 people in China per year (Zhang et al., 2016). The use of agricultural UAVs to apply plant protection products (PPPs) aids in mitigating the environmental and health effects of pesticide overuse.

Agricultural UAV applications are becoming more important, benefiting agriculture in terms of productivity, economy, and safety. A UAV can fly lower than a traditional fixed-wing aircraft. UAVs are capable of hovering in one place for a long time and are considerably smaller than other aircraft. All of this improves the accuracy, speed, and safety of applying pesticides. As a matter of fact, findings suggest that a UAV can apply pesticides up to five times more speedily than a traditional fixed-wing aircraft (Linn, 2015). Pesticide spraying precision and penetration is high for UAVs, and the daily operational area is approximately 20–50 ha, depending on the UAV used. This is approximately 30–60 times greater than manual pesticide applications. Pesticide use is reduced by at least 30% and water use is reduced by 90% when compared to traditional crop protection methods, lowering costs and pollution. Furthermore, separating humans and machines (the operator controls the UAV remotely), reduces the risk of pesticide poisoning and labour intensity while increasing operational safety (Zheng et al., 2018).

According to Liu and Guo (2019), who looked at how regulations on residues in crops affect pesticide residues globally, the EU, the USA, and Japan have developed the majority of the relevant legislative work. On the other hand, developing nations lack the resources and expertise necessary to create pertinent legislation or their legal systems are not yet sufficiently developed (Liu and Guo, 2019). It can be said that the development of agricultural UAV-specific regulations is proceeding at the same rate. The regulations applicable in the USA, EU, China, and Türkiye were compiled to examine the work of regional and national civil aviation authorities on agricultural UAVs. The similarities and differences between Turkish practices and those in other countries are highlighted in particular.

3 Agricultural UAV regulations review

Agricultural UAV deployments face a significant entry barrier due to the regulatory environment. We looked into the policies regional and national aviation authorities around the world have in place for the use of agricultural UAVs in this context.

3.1 The US

The Federal Aviation Administration (FAA) is an affiliate of the US Department of Transportation. It oversees UAV legislation and is in charge of enforcing it through civil penalties (Office of the Federal Register, 1998). Both a certificate of registration and a certificate of airworthiness must be present on every aircraft depending on factors such as MTOW and type of use, etc. According to their intended use, these are categorised into three groups (FAA, 2022).

Table 1 FAA UAV usage categories

<i>Public entity</i>	<i>Recreational/hobbyist</i>	<i>Commercial/business</i>
• This category is reserved for UAVs used by or for public/governmental entities.	• Covers only the recreational/hobbyist flights • Should be within the UAV visual range • UAV should not intervene in any manned air vehicle • Flying in controlled airspace at 400 feet or less and only with prior authorisation • Flying 400 feet or less in uncontrolled airspace • All flight wise restrictions should be adhered to • The UAVs heavier than 0.55 pounds (250 grams) should be recorded	• The Commercial UAV pilots should have a pilot certificate issued by FAA. • Any UAV scheduled for a flight must be registered with the FAA website • At takeoff, the UAV must weigh less than 55 pounds (25 kg) including the payload. • It should fly over G-Class airspace • The UAV must be within the visual range 1 • It should fly at 400 feet or less • It should fly at 100 mph (161 km/h) or • It should allow manned aircraft passage • It should not be flown from a moving vehicle unless in a sparsely populated area.

The FAA published detailed regulations governing the use of UAVs weighing less than 25 kg in 2016. The certification procedure and the use of UAVs are governed by such regulations under ‘Section 107’. The FAA provides the following examples to illustrate the difference between commercial and recreational/hobbyist use of UAVs with specific reference to agriculture:

The sole purpose of recreational or hobbyist UAV flight is education or entertainment. Examining a field to see if the plants require water falls under the category of recreational/leisure when crops are grown for individual pleasure.

UAVs are used in commercial and business contexts for activities like aerial inspection and photography services. The decision of whether crops are grown as part of a commercial farming operation requires irrigation is deemed as falling outside the scope of hobbies and entertainment.

Due to the preceding definitions, agricultural UAVs have always fallen under the 'Commercial/Business' categorisation in the US. Any UAV in this category is also known as a 'Light UAV'. The Code of Federal Regulations (CFR) Section 107 Part 14 applies to use and certification requirements in this category (FAA, 2016a). For instance, a light UAV must always be in the operator's visual line of sight (VLOS) and have a take-off mass of no more than 25 kg. Moreover, only daytime flight operations are permitted. A person with a 'pilot certificate' who is prepared to step in must assist the operator of a light UAV system. Candidates can receive a 'pilot certificate' if they meet the requirements listed below:

- must be at least 16 years old
- must have a good command of English speaking wise (reading, writing, speaking and comprehension)
- must pass an aviation knowledge test.

Candidates for UAV pilot must have passed the aviation knowledge test within the last 24 months. This implies that every two years, aviation knowledge should be 'renewed'. Light UAV flight operations are also restricted in the USA (FAA, 2016b):

- maximum airspeed – 100 mph (approximately 161 km/h)
- maximum altitude – 400 ft (approx. 122 m)
- maximum visibility range – 3 miles (approximately 4.8 km)
- vertical distance from clouds: 500 feet (152 metres) and horizontal distance: 2,000 feet (approx. 610 m).

UAVs, aeroplanes, and helicopters are commonly used for crop cultivation in the USA. Agriculture already has a higher yield due to the use of machinery, and UAVs are primarily used for mapping and data gathering for precision agriculture applications. In other words, UAVs are used in precision agriculture arm management and to improve harvest quality while maintaining or reducing input in production in the USA.

The FAA is establishing a set of rules to govern how farmers use UAVs in agricultural activities. This would be a significant aspect of integrating the technology into agricultural production, however, the massive delays in finalising the rules are a barrier to the potential benefits that UAVs can provide. Furthermore, the operational constraints specified/proposed in the regulations, while preferable to outright bans, are still extremely restrictive. As a result, there still is an opportunity for improvement (Linn, 2015). Despite the emergence of new UAV applications, aerial pesticide application regulations have yet to be updated. As a result, a commercial entity must currently obtain exemptions and permits for aerial pesticide application via UAV.

Most FAA regulations governing aerial pesticide application have not been updated in nearly 50 years. Some restrictions on UAVs can be waived, but not all, including those pivotal to pesticide application. UAVs, for example, are not permitted to transport 'hazardous materials' containing pesticides with active ingredients such as allethrin,

carbamate, and organophosphorus (Office of the Federal Register, 1998). Naled is one of the widely used aerial pesticides that is principally used to control mosquito populations. During the most recent Zika virus outbreaks in the southern USA, the use of naled has increased. Naled-based pesticides are prohibited from being carried by a UAV because they are organophosphates unless a specific, time-consuming exemption is granted. These restrictions are generally intended to reduce the risk of pesticides veering into non-target areas and potentially poisoning non-resistant adjoining crops or agricultural workers. The fact that a UAV can operate much closer to crops without causing damage, thanks in part to its lower thrust compared to larger manned aircraft, reduces the risk of drift (Petty and Chang, 2018).

Depending on the type of UAV used, a UAV operator must currently go through three exemptions and permitting procedures to be able to aerially distribute pesticides:

- 1 Exemption under Section 44807 is instructed for UAVs weighing more than 25 kg. This application is more pliable and has fewer constraints, but it is more expensive and takes longer to obtain. It is essential to note that Section 44807 Exemption only certifies the UAV while the pilot, like any other conventional aircraft, must be fully trained and certified by the FAA.
- 2 Section 107 authorisation applies for UAV authorisations. These permits are simpler to obtain and less expensive. Anyone may submit a permit application. However, “a comprehensive description of the envisioned operation and justification proving that the operation can be conducted safely under the terms of the permit” must be included in the permit application.
- 3 Last but not least, Section 11 ‘Exemptions’ offers exemptions from a variety of FAA regulations, but this procedure necessitates full notification for each applicant and is malleable.

3.2 *European Union*

Since 2009, the EU has outlawed all aerial spraying techniques, primarily for ecological reasons (Zwetsloot et al., 2018). Up until now, the regulation of UAVs with a MTOW of up to 150 kg has been left to the member states. In terms of restrictions or airspace classification, UAV legislation in the Member States varies significantly. Furthermore, some member states are currently updating or lack specific UAV regulations (Reger et al., 2018).

The EU published Commission Delegated Regulation (EU) No. 2019/945 on March 12, 2019, outlining the specifications that distributors, importers, manufacturers, and designers of unmanned aircraft systems must adhere to. The Commission Implementing Regulation (EU) 2019/947 of May 24, 2019, lays out the guidelines for pilots and operators using UAVs, as well as the types of operations and the regulatory frameworks that apply to each. According to Merz et al. (2022), the open (low risk), special (medium risk), and certified (high risk) categories of operations are as follows:

- Open (low-risk category):
Low-risk UAV operations with a maximum take-off mass of less than 25 kg, performed at a maximum altitude of 120 m above the ground or water and a safe distance from people and objects on the ground, and under the pilot’s direct vision.

Flight bans and restrictions in specific locations may be issued by competent authorities. If the UAV's altitude exceeds 50 metres, the pilot must indicate basic aviation awareness (EASA, 2018, 2019).

- Specific (medium risk) category:

When a UAV flies over people or shares airspace with manned aircraft, it is classified as 'specific'. The operator must perform a risk assessment and obtain approval from any national aviation authority.

- Certified (high risk) category:

UAV operations classified as 'certified' are highly dangerous. The requirements are similar to those of manned aviation.

The latest risk-based approach makes flights in low-risk UAV operations included in the open category easier. It also designates detailed requirements for both the UAV and the organisation of specific category UAV operations, such as flights beyond VLOS. The EU is made up of small and large-scale terrains, plains, and hilly terrain. Large machinery technology is common in the large, subdivided countries of Eastern Europe, as it is in the USA. Countries such as Germany, on the other hand, have primarily small-scale and few large-scale cultivated areas, but a large high-tech agricultural economy that already produces extremely high yields. Here, the emphasis is on resource conservation and environmentally friendly land use planning (Reger et al., 2018).

Roads, residential areas, environment-related areas, and so on are mostly directly adjacent to agricultural land, especially in a heavily populated country like Germany. Flying over these areas necessitates the permission of the landowner (for residential areas), the facility using the airspace (for example, airports or industrial facilities), and the National Aviation Authority. Airspace over private but uninhabited land is unreservedly passable, but a horizontal distance of at least 100 metres must be maintained from federal roads or railroads. When piloting a UAV, keep a horizontal distance of at least 30 metres from people and objects on the ground (buildings or vehicles, etc.).

In Germany, agricultural UAVs are in commercial use (Reger et al., 2018). Insurance is mandated for UAVs weighing more than 250 g, and the owner must tag the UAV with his or her name and address in indelible, fire-resistant written form. If the MTOW of the UAV exceeds 2 kg, users must hold a UAV license/certificate. This certificate is valid for 5 years, and commercial users must be at least 16 years old. A flight permit is necessary if the UAV has a MTOW of more than 5 kg and is operated within 1.5 kilometres of an airport boundary or at night (Mackeler, 2017).

3.3 China

China was the world's leading agricultural producer in 2017, with rice, maize, wheat, vegetables, and cotton at the top of the list. Crop maintenance, on the other hand, has a relatively high cost, including the overuse of chemicals, which causes soil degradation and water pollution. Furthermore, because the majority of agricultural workers are elderly, China faces a labour shortage. As a result, China extensively employs agricultural UAV technology. In China, agricultural UAVs are used at a rate of 95% for aerial spraying and 5% for data collection and analysis (Ipsos, 2019). The Chinese government supports farmers by providing subsidies for the purchase of UAVs.

UAV pesticide spraying from the air is legal in China (Singh et al., 2019). agricultural UAVs were first used in the Chinese agricultural industry in 2010. China had 695 agricultural UAVs in 2014, with a total operating area of about 284,000 hectares. The total operating area increased to approximately 769,000 hectares in 2015, and the number of agricultural UAVs increased to 2,324. By 2016, the number of agricultural UAVs had increased to 6,000, with a total operational area of 1.58 million hectares. More than 10,000 UAVs are currently in commercial use in China, where they, along with fixed-wing aircraft and helicopters, apply pesticides and fertilisers on more than 2 million hectares. Many aviation technology companies, pesticide manufacturers, service providers, and cooperatives have joined the industry, with some receiving explicit government support. More than 600 UAV businesses were registered in China as of the first half of 2017 (Xiongkui et al., 2017).

A pilot's license is not considered necessary for civil UAVs with a dead weight of 4 kg or less or a take-off weight of 7 kg or less. In the meantime, airspace in China is divided into three categories and managed separately: controlled airspace, preparatory airspace, and self-flying airspace. Civil UAV flights in preparatory and self-flying airspace "do not require any approval for flight airspace and flight plan." Flights weighing more than 0.25 kg but less than 7 kg, as well as non-military, police, or customs anti-smuggling operations, do not necessitate a flight declaration/permit (Yao et al., 2021).

The following is the current Chinese agricultural UAV business model (Chakreeves et al., 2014):

- Farm owners can purchase UAVs directly from manufacturers.
- Farm owners can use an entrepreneur's UAVs.
- Farmers can pick services based on their needs via an online platform.

3.4 *Türkiye*

UAV flight operations in Türkiye are developing in tandem with global trends. The most recent UAV legislation published by the Directorate General of Civil Aviation (DGCA) to ensure efficient, consistent, and secure flight operations of UAVs in Türkiye is the UAV Systems Instruction (USI). USI, Türkiye's first legal UAV legislation, was published in 2016. The USI has been revised four times since 2016.

The fourth revision was issued in 2020 to determine the procedures and principles governing the import, sale, registration, and registration of civil UAV systems to be operated or used in Turkish airspace, ensuring airworthiness, the qualifications required for those who will use the systems, air traffic services, and UAV operations (DGCA, 2018).

As of the first legislation, which went into effect in 2016, UAVs weighing more than 500 grams were required to be registered in Türkiye's UAV Registration system. (iha.shgm.gov.tr). According to Türkiye UAV legislation, the MTOW of UAVs used for civilian purposes is divided into four categories as shown in Table 2.

UAVs can be used in two ways in Turkish airspace. These are sportive/amateur and commercial. Those who will take flight commercially in Türkiye airspace must receive training from authorised training institutions. Such institutions can be either public or private. The data within the UAV registration system is periodically released via the

UAV registration system. The number of UAV pilots and registered UAVs in Türkiye would further increase by approximately 55% per year between 2016 and 2020 (Savas, 2022).

Table 2 UAV classification in Türkiye

<i>UAV class</i>	<i>Maximum take-off weight (MTOW)</i>	
	<i>Lower limit (inclusive)</i>	<i>Upper limit</i>
UAV 0	500 gr.	4 kg
UAV 1	4 kg	25 kg
UAV 2	25 kg	150 kg
UAV 3	150 kg	Larger

The ‘Flight Zones Map’, which was produced with the amendment in 2019, is the most significant development in Türkiye’s UAV legislation. As a result, it is designed to perform UAV flights systematically by making a safety-based dichotomy. As shown in the diagram below, Türkiye airspace is divided into three zones: red, green, and inert:

- zone subject to special permit (red)
- zone subject to permit (inert)
- flight free zone (green)
- permitted confidential area (confidential).

The airspace in which hobby (sportive or amateur) and commercial UAV pilots can fly is listed below in Table 3. Sportive or amateur UAV pilots can only fly in the free zone if they notify the appropriate local administrative authorities and ask for permission online from the UAV registration system. UAV pilots who can take commercial UAVs into the flight, on the other hand, can fly anywhere in Türkiye airspace by getting permission (Savas, 2022).

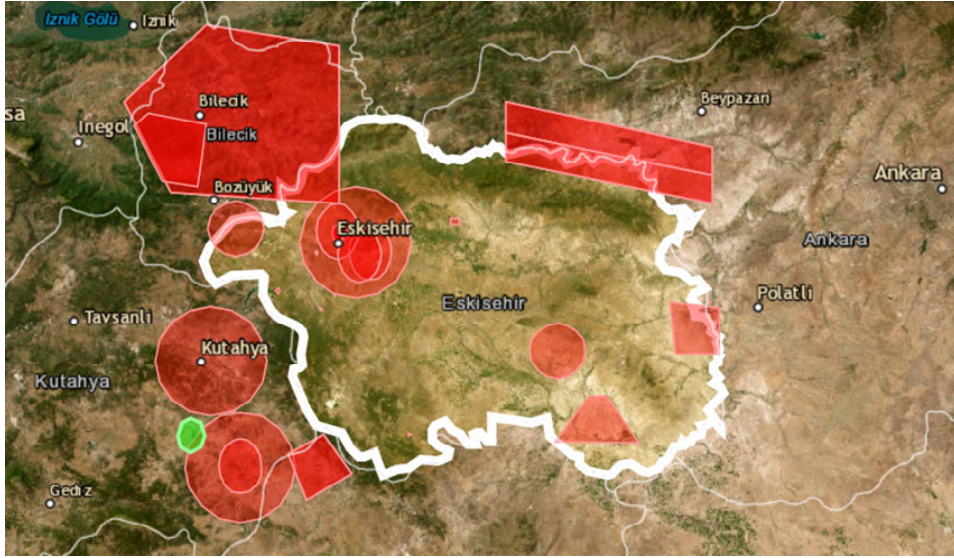
Table 3 Airspace use of UAVs in Turkey

<i>Airspace color</i>	<i>Airspace category</i>	<i>Flight purpose type</i>
Red	Zone subject to special permit	Commercial
Inert	Zone subject to permit	Commercial
Green	Free flight zone	Commercial and hobby
Hidden	Permitted confidential area	No flights

Flight zones in Türkiye are defined by the relevant local administrative agencies, the General Directorate of State Airports Authority, military units, and the DGCA. In Türkiye, there are roughly 1,000 designated green spaces and approximately 300 green spaces that have been approved and shown at flight zones maps (Figure 3). As a result, as of the study’s publication date, there are no flight-free zones in every region of Türkiye (in each province). Commercial UAV pilots must apply the UAV registration system 5 business days in advance for all types of flights (sportive/amateur – commercial) in their permitted zones. Commercial UAV pilots must apply 10 business days in advance using the UAV Flight Permit Request Form (FR-19) on the General Directorate’s official

website with the rational reason for any type of flight (sportive/amateur-commercial to commercial) (DGCA, 2022).

Figure 3 Flight zones maps of Türkiye (see online version for colours)



Flight permits are issued through DGCA's UAV registration system (iha.shgm.gov.tr), while applications for flights under 400 feet are reviewed by the relevant local administrative authorities and, if appropriate, NOTAMs are published. If a flight permit is produced, the operator/pilot/person must follow the provisions stipulated in the Turkish AIP as well as any other rules that are outlined. Any flight above 400 feet in the areas subject to permission requires an application at least 10 business days in advance using the UAV Flight Permit Request Form (FR-19) on the Directorate General's official website, along with the justification.

Agriculture control tools and equipment used in PPP applications within the scope of agricultural supervision processes are authorised by the Ministry of Agriculture and Forestry. According to the ministry's directive on this specific issue, applications made with unlicensed UAV systems and units of UAV systems are strictly prohibited. When using UAV systems to apply PPPs for agricultural control, a safety distance of at least 3 km must be left between pastures, residential areas, wetlands and the application area's borders.

Users such as manufacturers, professional practitioners, and licensed owner companies with certified competence under civil aviation legislation carry out PPP applications for pest control through UAV systems. License holders and users of UAV systems are responsible for any damage they cause to third parties within the scope of agricultural control and civil aviation legislation (Ministry of Agriculture and Forestry, 2022).

4 Conclusions

Regulations are currently being worked on or improved for UAVs, whose applications and many applications are growing daily all over the world. Regulations are being produced or expanded as UAV use expands, particularly in industries like agriculture that have significant social and economic benefits.

UAVs' maximum legal altitudes are generally between 100 m (Germany), 122 m (the USA), and 120 m (Türkiye). Similarly, UAVs are not permitted to fly within visual range, and night flights are prohibited. Such limitations and restrictions, however, can be removed with special permits, including in Türkiye. Most countries distinguish hobby/recreational and commercial uses. Insurance and a flight manual are considered necessary for commercial use. In most countries, commercial UAVs require a pilot certificate highlighting basic aviation training. In most countries, the minimum age for UAV use is 16, but in China and Türkiye, it is 18 (for UAV 1 and UAV 2 class UAVs).

A comparative table of the countries analysed was developed to provide an international comparison of UAV regulations, similarities, and differences (Table 4).

Table 4 Comparison of agricultural UAV regulation criteria

	<i>The USA</i>	<i>Europe</i>	<i>Germany</i>	<i>China</i>	<i>Türkiye</i>
Minimum take-off weight for UAV registration	250 gr	250 gr	250 gr	250 gr	500 gr
Distinction between hobby/entertainment and commercial use	✓	Risk based distinction	✓	-	✓
Maximum speed	161 km/h	-	-	100 km/h	-
Maximum altitude	122 m	120 m	100 m	120 m	120 m
Insurance requirement	✓	✓	✓	-	✓
Requirement for flight permit	✓	✓	✓	✓	✓
Pilot certification	✓	✓	✓	✓	✓
Minimum age limit	16	16	16	18	18
Requirement for aerial spraying permit	✓	✓	✓	✓	✓

In general, the heavier the UAV to be used, the more technical or regulatory constraints it is subject to. This is due to the classification and assessment of potential hazards frequently dependent on a UAV's MTOW. In addition, whether or not the area to be airlifted is densely populated, its altitude, speed, and mission all make a significant contribution to the potential risk.

When compared to a small UAV over residential areas, the use of UAVs with a large MTOW over crops and meadows has a lower risk classification. Damage from a UAV accident is much less severe given that they are flying over a lake, a field, or the sea, and there are no people nearby. Because agricultural UAVs are used in areas with low to no human density, privacy issues are not brought up.

Current UAV control requires the pilot or any support person to keep constant eye contact with the UAV. This is the case for our country and the other countries under investigation. Although this has a significant impact on the potential uses of UAVs, it is intended to ensure the safety of agricultural UAV operations. This is especially true when using agricultural UAVs over large tracts of land and meadows. This is because arable land can stretch for hundreds of metres or even kilometres. When spraying from the air over a large agricultural area, a UAV pilot may end up losing visual contact with the UAV. If agricultural UAVs are travelling autonomously in this case, the flight operation will proceed. However, in Türkiye, autonomous flight beyond visual range is not permitted. Autonomous UAV flights are permitted in the USA as long as they maintain visual contact with the operator at all times. In general, all countries disallow the use of UAVs at night. Local aviation authorities may grant exceptions or authorisations in Türkiye and other countries for UAV flights above 120 metres and at night.

An international comparison of rules regulating the use of agricultural drones UAVs is provided in the contents of this study. In less developed or developing countries, there may be more latitude in the rules and regulations governing UAVs. One of the most significant criteria for UAV flights, according to the findings, is the agricultural UAV's maximum takeoff weight. In general, the use of agricultural UAVs with a MTOW of over 25 kg is aggressively expanding in other countries, such as Türkiye. The advantages and disadvantages of applying pesticides manually or using a ground-based machine (a tractor, for example) have not yet been thoroughly examined scientifically. In this regard, a study will be conducted in the upcoming years to find out whether UAVs used for aerial spraying have any positive or negative effects on our health or the economy.

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