



Review

Peculiarities of Unmanned Aerial Vehicle Use in Crop Production in Russia: A Review

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Abstract: This review article examines the potential for intensifying Russian crop production through digital transformation, particularly through the use of unmanned aerial vehicles (UAVs). (1) The importance of this topic is driven by declining food security in some parts of the world and the Russian government's goal to increase grain exports by 2050. (2) Comparisons of agriculture technologies suggest that the use of UAVs for crop treatment with agrochemicals is economically effective in certain cases. (3) Specifically, UAV treatment is advantageous for plots with irregular shapes, larger than 2 ha, and containing between 9 and 19% infertile land. It is also important to agree on the flight parameters of the UAV, such as speed and altitude, as well as the type of on-board sprayer and agrochemical. In case of insufficient funds or expertise, it is recommended to hire specialized companies. (4) The listed peculiarities of Russian crop production led to assumptions about the regions where the use of UAVs for agrochemical treatment of crops would be economically effective.

Keywords: UAV; crop production; differentiated plant treatment technology; aerial spraying



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1. Introduction

The introduction of new technologies usually prompts experimentation in practical contexts, and unmanned aerial vehicles (UAVs) are no exception. Currently, a number of UAV applications are known, usually including surveillance and control tasks, telecommunication tasks, etc. [1–9]. In recent years, UAVs have become an important tool in agriculture [10–16]. They are used for precise application of herbicides and fertilizers on crops [17–20], generation of high-quality digital maps of fields [21,22], monitoring of pasture areas, and other tasks [23–29]. A variety of geographic, regulatory [30], and other factors [31–33] influence the use of UAVs. At the same time, the introduction of UAVs in agriculture should be accompanied by a thorough analysis of the technical and theoretical aspects of agricultural technology [34–37], taking into account both the degree of implementation and the areas of application [38–40]. The importance of these studies for Russia arises from the elimination of technical services and training farms in agricultural research institutes, similar to the American Extension Service, during perestroika. These institutes played a crucial role in evaluating and formulating recommendations for scientific and technological progress [39]. By 2010, crop rotations were not followed consistently on 75% of arable land, and fertilizer doses were reduced by a factor of 2.2 (from 88 to 38 kg/ha). In addition, the use of chemical plant protection agents (PPA) was reduced by a factor of 9. As a result, grain yields in the country remained at almost 2 t/ha, while this indicator reached the level of 7 t/ha in the UK, France and the USA [41].

In January 2010, the Russian government adopted a plan to intensify agriculture, as outlined the Food Security Doctrine [42]. This plan was further supported by the Long-term Strategy for the Development of the Grain Complex [43], adopted in August 2019. The documents discuss various factors that contribute to the intensification of agriculture, such as the level of development of industrial sectors that provides agriculture with means of production and equipment; the level of development of science, technology,

and production technology; the level of qualification and culture of personnel; natural and climatic conditions; soil fertility; farming; and animal husbandry culture. It is obvious that these factors play an important role in the intensification of agriculture.

The listed factors have produced tangible results. For example, the mineral fertilizer application rates increased to 60.5 kg/ha in 2017, resulting in improved soil fertility. This led to grain production of 113.3 million tons in 2018, including 72.1 million tons of wheat [44]. According to the U.S. Department of Agriculture, Russian wheat exports totaled 43.5 million tons in March 2023, 15 million tons more than the second largest exporter, Australia. However, while Russian agriculture produces high grain yields, it still lacks advanced technology and remains extensive, according to [40]. Based on previous research [40], the use of extensive management techniques leads to the rapid degradation of arable land, and its removal from production. Research has shown that some farms may experience losses of up to 30%. Therefore, it may be beneficial to consider updating agricultural technologies to increase grain crop exports. The Long-term Strategy [43] proposed by the Russian government suggests the introduction of digital technologies in agriculture as a possible solution to achieve this goal. At the initial stage, in 2017, the adoption of precision agriculture technologies was not as rapid as expected, and as a result, in 2018, only 10% of arable land was cultivated using digital systems. This can be attributed to the need to take into account the economic peculiarities of the country's development, as well as to comply with environmental protection requirements [44]. Assessing the likelihood of soil contamination caused by the use of highly toxic PPAs in precision agriculture technologies can be a complex matter.

In November 2023, in response to the economic situation in Russia, the Strategic Direction of Digital Transformation of Agro-industrial and Fisheries Complex [45] was adopted. The document proposes the introduction of new means of production automation, such as robotic systems, including unmanned aerial vehicles, to increase efficiency. As is well known, these units are being used worldwide to address the problem of highly skilled rural workers migrating to cities, which is commonly referred to as urbanization. This is supported by a report from Future Market [44], which indicates that the average annual growth rate of agro-robots in the global market is 11.2%, with an expected market value of \$40 billion by 2026.

The adopted documents provide solutions to strategic issues related to the intensification of agricultural sectors. However, actual producers face specific challenges regarding the economic efficiency of implementing digital technologies, such as UAVs, in agriculture.

This leads to the following research questions:

- Is there still a need to maintain the production of large quantities of grain in Russia?
- What are the strategies that can be used to not only maintain but increase grain production levels beyond 2022?
- What are the unique features of improving Russian agriculture via digital transformation?
- What distinguishes the use of drones for crop production in Russia?

The structure of the review was determined by the above questions. Section 2 provides evidence for the intensification of agricultural development in the Russian Federation and assesses the potential for a significant increase in agricultural production. Section 3 outlines the implementation of precision farming technologies in Russia, analyzing the correlation between the technology type and farm size. It also examines the specifics of ultra-low volume (ULV) spraying technology and the types of machinery used to implement ULV technology in Russia. Section 4 assesses the regulatory framework governing the use of precision equipment in agriculture, analyzes different types of Russian agricultural producers, evaluates regulatory restrictions on the application of UAV technology, develops UAV strategies for the Russian market, and examines the economic impact of UAV use in crop production. In addition, this section includes a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis of UAV application in crop production in Russia. To assess the effectiveness of UAVs in crop production, we will use the traditional measure of

production intensification, namely the monetary cost per 1 ha (production cost). However, our comparison will be limited to the effectiveness of treating crops only with PPA.

2. The Necessity of Agriculture Intensification in Russia

2.1. Quantification of Food Security in the World Regions

To justify the necessity of intensification of agriculture in the Russian Federation in spite of the declining population, we will base our argumentation on the concepts of state economic security and food security [44–51]. As shown in these works, these problems are caused by the process of the predominance of the urban population over the rural population [52–55], depletion of fertile land, population growth in a number of countries, and others. As a result, there is a gap between the capabilities of modern agriculture and the needs of the growing population. According to [52], this problem will become increasingly severe by 2050 due to the disparity between nations that produce agricultural goods and those that have a critical demand for them. The complexity of solving this problem lies in this gap. Figure 1, based on data from [52], shows an assessment of world regions based on food security criteria.

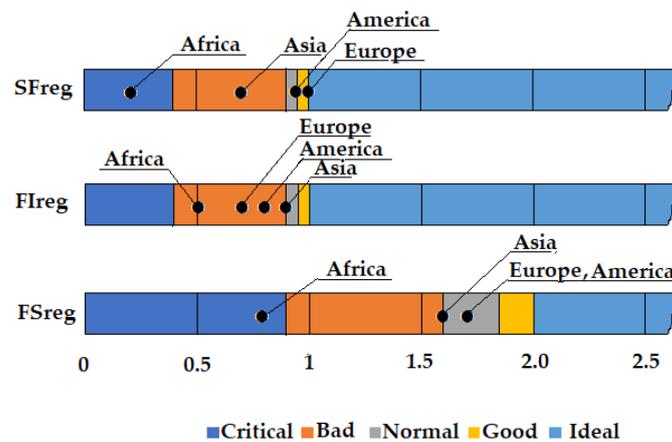


Figure 1. Evaluation results of food security indicators in different regions of the world [52].

According to the methodology [52], the quantitative assessment of food security involves the identification of three indicators: the region’s food security indicator FS_{reg} , the region’s food independence indicator FI_{reg} , and the region’s food self-sufficiency indicator SF_{reg} . These indicators are linked by the ratios

$$FS_{reg} = FI_{reg} + SF_{reg}, \tag{1}$$

$$FI_{reg} = S_{food} / I_{food}, \tag{2}$$

$$SF_{reg} = S_{food} / D_{food} \tag{3}$$

where S_{food} is the amount of food produced in the region, I_{food} is the amount of food imported into the region, and D_{food} is the amount of food consumed in the region.

According to Figure 1, the United States and European countries, including Russia, are classified as states with a normal level of the food security indicator ($FS_{reg} = 1.7$) and a good level of the self-sufficiency indicator ($SF_{reg} = 0.9$ and 1.0 , respectively). To achieve a standard level of food security ($FS_{reg} = 1.6$) in Asian countries, food export is the only viable option, despite the region’s normal food independence indicator ($FI_{reg} = 0.9$). The food situation in Africa is much more complex. With an average annual population growth rate more than 2% since 1952 and currently at 2.52% [53], the level of food security is $FS_{reg} = 0.8$, which is poor even taking into account imports. Moreover, the indication of self-produced goods is also weak, with SF_{reg} not exceeding 0.3.

Thus, a significant increase in food exports is required by 2050 due to the projected growth of the world population in African countries. This will also reduce the likelihood of uncontrolled migration flows from Africa to more developed countries.

2.2. Assessing the Possibility of Significantly Increasing Agricultural Production in Russia

Russia is one of the world’s major agricultural exporters, along with Australia, the United States, and several Western European countries. In this context, let us assess its ability to increase agricultural production. In this case, we will limit our analysis to crop production. The evaluation of food safety focuses on the products obtained from this sector, including those that are produced through its processing [49]. Therefore, our scope is limited to this specific area. When analyzing agriculture, it is important to keep in mind that although the principles of agriculture are generally applicable, each country is unique due to various natural and social factors.

Currently, scientific and innovative support for agriculture is focused on creating adaptive landscape farming systems [46,56,57] implemented in agricultural technology packages. Table 1, compiled from data from [56], provides a concise overview of the main characteristics of these technologies.

Table 1. Agricultural technology packages in the context of adaptive landscape systems [56].

Agricultural Technology Packages	Main Difference	Major Drawbacks
Extensive	Use of natural soil fertility with tolerant varieties	Soil degradation and depletion
Normal	Use of more productive, adaptable varieties and application of fertilizers for deficit-free nutrient balance	Measures to protect soils from water and wind erosion, agro-technical and chemical soil improvement
Intensive	Achieve planned yields from intensive varieties with high genetic potential and specified product quality	Use only on relatively favorable, ameliorated, cultivated soils (ideal conditions)
High (precision)	Optimal control of the production process through remote and information systems and precision machinery. Not only yields and product quality are determined, but also the optimal composition of trace elements. Use of crop rotation, tillage, fertilization, and plant protection agents (PPA) to maximize the potential of the varieties.	Application on plots that are homogeneous in terms of growing conditions (normative contrast, complexity of soil cover and other indicators)

Extensive technology use is currently being restricted due to its negative impact on soil depletion and degradation. In Russia, this has resulted in 44.9 million hectares of unused land across all categories, equivalent to 12% of the total land area in 2019 [55–58]. In addition, the conversion of land for residential, commercial, and industrial purposes leads to a reduction in arable land. The impact of these two factors has significantly reduced arable land in Russia by 264.7 million hectares (41%) and in Europe by 23.03 million hectares (80.4%) between 1990 and 2019. The implementation of a normal agricultural technology package requires the use of specific breeding strains that require in-depth, specialized research.

The most promising approach to significantly increasing agricultural yields is through high (precision) agricultural technologies. Table 2, compiled from data taken from [40], shows the effects obtained from their application.

The term high (precision) agricultural technologies used in Tables 1 and 2 includes more than precision agriculture (PA) [31–33], according to V. Kiryushin [40,56,58]. This broader term includes not only tools, as found in PA, but also effects such as new crops and intensive varieties, biological crop rotations, flexible management of crop nutrition and protection, minimized soil tillage, and widespread use of biotechnologies.

Table 2. Advantages of high (precision) agricultural technologies [40].

Agricultural Tools	Positive Impact of Implementation
Parallel driving	Time and fuel savings; Increased productivity and quality of work
Differentiated seeding	Increased yield due to better seed density; Lower seed costs
Differentiated fertilization	Yield increase; Fertilizer savings
Differentiated weed spraying	Yield increase; Herbicide savings
Differentiated irrigation	Nutrient savings; Water savings
Differentiated tillage based on soil maps	Energy savings; Improved machinery efficiency
Pre-harvest chlorophyll measurement in crops	Improved product quality; Optimal harvest start time

All this, taking into account the results of works [40,58–61], allows for a scientifically substantiated answer to the question formulated in Section 2.1 about the possibility of Russian agriculture to double grain production by 2050. The production of 300 million tons of grain per year, which is 2.2 times more than the level in 2022, can be achieved with the use of three agricultural technologies: normal, intensive, and high (precision), in addition to the application of 15 million tons of mineral fertilizers. Currently, Russian agriculture uses the first two technologies. The high (precision) agricultural technology is currently being implemented. Table 1 illustrates the significant use of precision agricultural equipment, such as UAVs. Our analysis focuses only on PA and its tools, in particular PA characteristics.

3. Peculiarities of PA Implementation in Russia

As the analysis of foreign and Russian studies shows, PA follows specific patterns. This article examines its main features in detail.

3.1. How Farm Size Affects the Type of PA Technology Used

Analysis of the data in Table 2 suggests that the use of high (precision) agricultural technology has the greatest impact on homogeneous plots. The size of these plots varies considerably depending on the geographical location and climate of the area. The PA implementation in different countries has shown a correlation between farm size, financial capacity, and the specific PA strategy adopted [10–14]. Tables 3 and 4, taken from [13] and [62], respectively, provide an overview of the methods and tools used in these strategies.

According to most experts [38], PA is primarily associated with the differentiated application of fertilizers and the treatment of plants with pesticides. It may be worth considering the possibility of using UAVs for this purpose.

The PA tools are based on information technologies, as the data in Tables 3 and 4 show. It is essential to emphasize the fundamental role of digital maps of treated fields, which act as a database for all technological operations in precision agriculture. Maps differ in the systems used to create them and in their intended use. For example, Geographic Information Systems (GIS) and Vision Control Systems like Leaf Color Chart (LCC) generate maps to assess crop health through leaf color analysis. Global Positioning System (GPS) navigation systems create maps to determine the optimal routes for field processing. Remote Sensing (RS) systems create maps to assess soil fertility and other related factors.

Table 3. Common adoption strategies for precision agriculture (PA) for developing countries [13].

Strategic PA Adoption Component	Technologies	Target Sector
Single PA technology	Single low-level PA technologies, Leaf Color Chart (LCC), small machine-based virtual reality technology (VRT), etc.	Small-scale farm
PA technology package	Signal passed at danger (SPAD), LCC, decision support system (DSS), geographic information system (GIS), VRT, Global Positioning System (GPS), etc.	Consolidated plots, plantation crops, cash crops, cooperative farming, etc.
Integrated PA techniques	On-line sensor, image processing, remote sensing (RS), yield monitoring system, VRT, GPS, etc.	Organized farming sector

Table 4. Methods of digital transformation in the Russian agro-industrial complex [62].

Methods	Contents
Internet of Things (IoT) sensor application	Automating the microclimate in greenhouses throughout the agricultural process; automating the control of climatic parameters in agricultural fields
Light-emitting diode (LED) technology	Optimizing greenhouse growth in countries with limited arable land
Solar cell application	Reducing energy costs for farm/business by harnessing solar energy
Use of robots	Replacing workers in high-producing, skill-scarce regions with robots to care for crops and animals
Unmanned aerial vehicle (UAV) and satellite application	Spraying insecticides and fertilizers and monitoring field conditions
Internet, mobile phone, and cloud computing application	Using big data and other agricultural databases to obtain information on the condition of fields and to search for recommendations on the implementation of agricultural processes

3.2. Characteristics of ULV Spray Technology

Modern agricultural technologies, such as PA, acknowledge that PPA and fertilizers have a specific dosage that positively affects plant growth [63–72]. However, exceeding these standards does not increase the biological effect and harms the environment, resulting in unnecessary treatment costs. Table 5, from the cited source [64], provides information on recommended application rates for various herbicides. In addition, Table 6 outlines the ideal droplet size required for herbicide spraying, resulting in the complete eradication of insects and plant diseases [65,66]. Most large farms in Russia with extensive acreage typically use traditional ground machines for spraying. This method involves applying high solution rates, ranging from 100 to 300 L per ha [66–68], with large droplets of low concentration, which is believed to reduce crop stress.

Table 5. Herbicides and their active ingredient rates applied during the spray testing in 2021 and 2022 [64].

Stage of Application	Herbicides	Active Ingredient	Rate (L/ha)
Pre-Emergence	Prowl	Pendimethalin	1.006
	Valor	Flumioxazin	0.110
	Strongarm	Discosumlam	0.010
Post-Emergence	Cadre	Imazapic	0.070
	Dual Magnum	S-metolachlor	0.900
	Butyrac	2,4-dochloro-phenoxyacetic acid	0.900

Table 6. Optimal droplet size of plant protection agent (PPA) for 100% insect and disease control [66–68].

PPA Purpose	Optimal Spray Droplet Size, μm
Flying insect control	10–50
Surface insect control	30–150
Crop disease control	30–150
Weed control	100–300

Analysis of the data in Tables 5 and 6 and comparison with conventional application rates shows the importance of the ULV spraying technology. Speed-adaptive variable-rate spraying is a type of technology that allows spray droplet size to be adjusted [68–72]. When ULV technology is used, it is believed that the crop impact of PPA application is achieved with 10–100 μm droplets, as opposed to the conventional large droplets of 600–700 μm diameter [65,66]. The spray pattern produced by the smaller diameter PPA droplets is more uniform.

Reducing the droplet size of PPA has become a pressing issue due to restrictions or bans on aerial application of pesticides in several countries, including the United States, China, and EU countries [67]. For example, the use of aerosol sprayers, including UAVs, is completely banned in all EU countries. Drone spraying is allowed in several U.S. states, as long as operators strictly adhere to the Federal Aviation Administration (FAA) operating rules and pesticide application requirements. In China, agricultural pilots are required to complete Class V crop protection training.

3.3. Analysis of the Equipment for the Implementation of ULV Technology in Russia

In addition to UAVs, the ULV technology applied in Russia mainly uses small airplanes such as the Cessna, Bekas, and an AN-2, and motorized gliders such as the T-2M and Veterok. Currently, light aircraft and motorized gliders are responsible for up to 80% of grain crop cultivation [54], while UAVs manage only 1–2% of the total cultivated area.

3.3.1. Implementation of ULV Technology Using Light Aircraft and Motorized Gliders

Light aircraft are equipped with Micron centrifugal sprayers [66] mounted from below at a low angle to the ground. This setup allows the directional spray pattern to be adjusted toward the upper surface of the crop being treated. The pesticide solution is dispersed through a metal mesh. The size of the droplets can be varied by adjusting the speed of the rotating drum and the amount of liquid being fed into the drum. At low flight heights of 1–3 m, the integration of adjustable fan blades creates turbulence to treat both the top and the bottom of the leaf plates. As a result, this technique produces a form of vertical spraying that is essential for several crops, such as corn and soybeans, as discussed in [18,21].

The use of motorized glider sprayers on for ULV technology has several drawbacks:

1. The inability to hover, which eliminates the ability to extend treatment time on specific areas;
2. The spray stream is directed at an angle to the ground surface, resulting in a reduction in the reflected spray intensity when a vertical spraying mode is generated;
3. Inadequate pilot protection against strong pesticides.

Among the main advantages of the sprayer, two benefits are emphasized by manufacturers [66]:

1. The ability to adjust the droplet size from coarse to fine;
2. The adaptability to a wide range of aircraft and ground equipment.

A comparable ground equipment sprayer shown in [64] produces droplets ranging from 106–502 μm , but lacks the ability to perform vertical spraying.

3.3.2. Implementing ULV Technology with UAVs

There is great potential for implementing ULV technology in agriculture through the use of agricultural UAVs, which have unique capabilities compared with other unmanned

aerial vehicles. Table 7, based on data from [72], shows the characteristics of UAVs used in Russian agriculture.

Table 7. UAV brands used for the precise application of liquid pesticides, fertilizers, and herbicides in Russia [72].

Description	China/DJI/Agras MG-1	China/DJI/Agras T30	China/DJI/Agras T40	Japan/Yamaha/YMR-01	Japan/Yamaha/Fazer R
Configuration	Octocopter	Octocopter	Octocopter	Hexacopter	Single rotor helicopter type
Working load, L (kg)	10 (10)	30 (40)	40 (50)	2 × 12 (24)	32 (30)
Productivity, ha/h	3–4	16	21	4	4

Based on Table 7, it is apparent that the majority of agricultural UAVs use a multi-rotor configuration with a spraying mechanism located underneath. The cost of these devices ranges from RUB one to two million.

The multi-rotor design of UAVs and their hovering capabilities allow the application of various modes of PA technology for crop spraying purposes [11]. These modes include regular rate spraying, prescription spraying, real-time variable rate spraying based on target detection, and smart spraying.

Droplet size control. Similarly to the Micron sprayer, the droplet size is influenced by the rotational speed of the centrifugal nozzle with the airflow created by the rotor blades [37]. As the speed increases, smaller droplets are produced.

Vertical spraying. This configuration of nozzles and rotors allows for more efficient implementation of vertical spraying technology than the Micron centrifugal sprayer. To achieve the desired result with UAVs, two aerosol streams containing PPA are pressurized [22,70,71]. The first stream is generated by nozzles and directed downward toward the ground surface by the rotors. The second stream is generated by reflection from nearby ground and moves upward. Unlike Micron, the first stream is directed vertically downward rather than at an angle. The trajectory of the second stream is influenced by atmospheric conditions such as wind speed and direction, as well as the internal pressure of the stream. Regulating the flow pressure requires changing the altitude, nozzle pressure, and nozzle shape (a pressure-swirl nozzle). Nozzle positioning affects both the angle of the spray cone produced and the size of the droplets. According to reference [37], placing the nozzle directly under the working rotors reduces the spray cone from 80 to 56 degrees. This reduction is an important factor to consider as it affects the coverage area. Modifications to the flight altitude of the UAVs are made as needed.

Selective field treatment. The technical design and equipment of UAVs allows them to treat areas with varying intensities, including individual patches [11,23]. On-board video systems detect weeds, and, based on real-time analysis, operators activate the pulse-width modulation (PWM) mode to control the opening and closing times of the solenoid valves on the sprayers.

Fluid flow, spray uniformity, and working width control. As shown in [7,11,35], these parameters are controlled by the flight speed and altitude of the UAV. In [11], it is shown that by varying the UAV flight speed in the range of 10 to 50 km/h and the flight altitude from 1 to 5 m, it is possible to control the fluid flow from 1 to 5 L/min. In addition, the rate of pesticide deposition can be adjusted in the range of 30 to 0.24 g/m².

The coverage area of the UAV is determined by its flight altitude. When equipped with a nozzle spray angle of 53 degrees, the width of the coverage area is equal to the distance of the UAV from the ground.

Table 8 from [7] illustrates the correlation between altitude and the volume of liquid deposited while flying at 10 km/h. In addition, Table 9 [7] shows the effect of fluid flow, flight speed, and altitude on the thickness of the film produced by the PPA.

Table 8. Surface coverage (g/m²) at flight speed of 10 km/h on flight altitude (1–5 m) and fluid flow (1–5 L/min) [7].

Fluid Flow (L/min)	Flight Altitude (m)				
	1	2	3	4	5
5	30	15	10	7.5	6
4	24	12	8	6	4.8
3	18	9	6	4.5	3.6
2	12	6	4	3	2.4
1	6	3	2	1.5	1.2

Table 9. Layer thickness (μm) at flight speed of 10–50 km/h on flight altitude (1 and 5 m) and fluid flow (1 and 5 L/min) [7].

Flight Altitude and Fluid Flow	Flight Speed (km/h)				
	10	20	30	40	50
Flight altitude 1 m, fluid flow 5 L/min	30	15	10	7.5	6
Flight altitude 5 m, fluid flow 1 L/min	1.2	0.6	0.4	0.3	0.24

By analyzing Table 9, it is evident that the thickness of the film containing the PPA can be adjusted by increasing the speed and altitude of the UAV. This relationship is explained in [35], where the opening of the spray cone changes in response to increasing speed or altitude, which ultimately changes the coating surface and subsequently the film thickness. The accuracy of the data presented in Tables 8 and 9, and therefore the conclusions drawn, are supported by field experiments [11,72]. These experiments show that the optimum agreement between the fluid flow and flight speed (with an error of no more than 1.9%) occurs at a flight speed range of 2.88–20.88 km/h.

3.3.3. Difficulties in Implementing ULV Technology with UAVs

Previous research on the use of UAVs in agriculture, including references [72–81], concludes that selecting the optimal flight path is critical for effective precision spraying, resulting in significant savings of time and resources. In this case, the problem at hand involves overcoming challenges such as:

- Eliminating the flight time limitation, which was previously about 10–20 min due to battery capacity;
- Determining the exact spatial position of the UAV;
- Developing an optimal flight path in terms of both time and cost, taking into account the spatial position of the UAV relative to the digital terrain map and the unique characteristics of different parts of the field.

The first problem has been successfully addressed by the implementation of additional batteries. Several alternative techniques are mentioned in academic literature, including references such as [74–77]. These methods use a number of different operating principles, ranging from gust-flying [75], energy transfer through laser beams [76], or charging stations within sensor networks [77]. In our opinion, in situations common in Russia where agricultural fields are far from transportation hubs and additional batteries are needed to prolong UAV operations, the ideal approach is to install charging stations on overhead power lines, as recommended by the Aerial-Core project [74].

The second issue, determining the exact location of the UAV, can be addressed using a variety of approaches. Two commonly used methods are:

- Obtaining data from global navigation satellite systems (e.g., GPS, GLONASS);
- Using information obtained from ground-based positioning systems, including satellite communications base stations.

The difference in accuracy between the two positioning methods is significant. The first method results in large errors measuring several meters, especially in the vertical plane [79,82], while the second method achieves a horizontal accuracy of 1–10 cm and a vertical accuracy of 15 cm. Therefore, the first method is unsuitable for agricultural UAVs flying at low altitudes, no more than 5 m.

The third task is currently under development and the solutions depend on the size of the areas to be routed. For smaller areas, [32] shows the use of Voronoi diagrams. These diagrams enclose the region with circles whose centers lie within the stressed regions. The circles indicate the points where the UAV must perform processing. The coordinates are computed from a digital map of the area, and the routing path is determined by solving the traveling salesman problem. Another approach is proposed in [22,78], which is ideal for selecting mandatory points for UAV visits in larger rectangular fields. However, the literature presents different approaches to optimal routing. In [22], the implementation of neural networks is proposed as a possible solution, and the possibility of adjusting the altitude of the UAV is also considered.

3.3.4. Comparative Analysis of Light Aircraft and UAV Capabilities for Implementing ULV Technology

Let us summarize the data presented in Table 10 to simplify the selection of suitable equipment for the application of PPA and fertilizers on a particular farm.

Table 10. Technical means for applying plant protection agents (PPA) and fertilizers.

Index	Terrestrial Towed Units	Small Aviation (Motorized Gliders)	Agricultural UAVs
PPA consumption, L/ha:			
• unregulated	250–400	50–100	10–15
• regulated	187	0.3–0.5	1–15
Speed, km/h	9.7–22.5	40–60	10–50
Mounting height, m	<1	1–3	1–5
Volumetric droplet diameter, μm			
• unregulated	600–700	600–700	100–250
• regulated	106–502	50–502	30–250
Deposition rate, g/m ²	1000	0.24–30	0.24–30
Coverage width, m	5.5	10–30	1–5 *
Side effects:			
changes in soil density due to uncontrolled machinery movement in the field	+	–	–
crop loss due to movement	+	–	–
ecological degradation due to the spread of PPA on roads and beyond the field boundaries, combined with the exceeding of required rates	+	+	–
weather dependent processing	+	+	+
pilots are not adequately protected from highly toxic PPA	+	+	–
short flight duration	–	–	+
low lift capacity	–	–	+

* When using a 53-degree nozzle spray angle.

4. Regulatory and Legal Assessment of UAVs in Russian Agriculture

In the previous section, we examined the advantages and disadvantages of UAV use in crop production and identified peculiarities in the Russian context. However, a comprehensive analysis of UAV use in other countries [12–14] underscores the importance

of considering the regulatory component of this issue. For example, in the United States, the requirement to obtain a UAV operator's certificate has significantly limited the use of UAVs in agriculture. Based on the results presented in reference [12], only 5% of farmers who use aircraft for crop treatment choose to use UAVs, with the majority preferring small aircraft instead.

In Russia, the regulations on the use of UAVs are more comprehensive [83–85]. These regulations specify both the regions and permitted times for UAV use [84], as well as the duration and time of day for treating fields with PPA [85]. In particular, the regulations require that UAVs weighing between 0.150 kg and 30 kg be registered with state authorities within 10 days [83–86].

We now analyze the impact of regulatory restrictions on the use of UAVs in Russian agriculture.

4.1. Typology of Agricultural Producers in Russia

We begin our analysis by examining the types of farms used by potential users, particularly those that are typical of Russia. In the Soviet period, the main landowners were kolkhozes and sovkhozes, which were cooperative associations of peasants and state-owned enterprises, respectively. Both types of farms used the land for free. However, the quality of agricultural land deteriorated due to the use of extensive technologies [87], as land users had no property rights and therefore no incentives to maintain the land. Economists predicted that the introduction of private land ownership in the late 1980s would attract more investment in agro-industrial complexes. However, the main result of the changes in the land sector in the last two decades (1990–2014) has been the full implementation of market relations. One negative effect of this process is that new landowners often fail to address negative agrarian issues, such as soil erosion, and neglect to invest in improving the fertility of agricultural land.

Since the 1991 land reform in Russia, researchers have identified three different categories of agricultural commodity producers [39,49]:

- Agro-industrial complexes (AICs);
- Private households (PHs);
- Peasant (farm) households (PFHs).

These farms vary in terms of the size of the agricultural land and the material and financial resources [39]. It is worth noting the difference between the institutional interpretation of Russian farms and the Western approach. In Russia, peasant (farm) households are engaged in commercial rather than entrepreneurial activities and are not focused on extensive reproduction. The proportions of different types of producers change over time. The dynamics of the process between 2001 and 2021 is illustrated in Figure 2 [49], and Figure 3 [49] shows the distribution of farm types in Russian regions in 2021.

According to Figures 2 and 3, the agro-industrial complex, rather than households in the agricultural sector of the European Union [88], is the main producer of agricultural products in Russia. Conversely, peasant (farm) households in Russia have produced only 16% of agricultural products as of 2021, compared with 80% in other countries. In addition, the agricultural sector is actively engaged in exports, accounting for nearly 60% of production, which is highly capital intensive. The production structure of agriculture in Russia from one Federal District (FD) to another, with the Central and North-Western FDs accounting for the largest share (over 70%) of the agro-industrial complex. Conversely, the Southern FD, which is characterized by a favorable climate and productive soil, has the highest percentage (24%) of peasant (farm) households. Notably, the Far Eastern FD has the largest share (50%) of private households.

Thus, the composition of agricultural enterprises in Russia varies in terms of size, territorial extent, and weather conditions.



Figure 2. Dynamics of changes in the structure of agricultural production by type of farm, % of total [49].



Figure 3. Regional structure of agricultural producers by type of farm as % of total [49].

4.2. Legal Restrictions on the Technical Use of UAVs

The most recent government decree in Russia [86] imposes two types of restrictions on the use of UAVs: general restrictions, which apply to all flights, and specific restrictions, which dictate how PPA should be applied to fields.

General restrictions include the following.

- UAV flights are only permitted in certain regions. Specifically, flights are permitted or may be permitted with government approval for specific civilian missions in the territories of the Republic of Tatarstan, the Altai and Stavropol Krai, Astrakhan, Volgograd, Voronezh, Lipetsk, Nizhny Novgorod, Novosibirsk, Saratov, Tambov, and Ulyanovsk regions. Figure 4 shows the geographical location of the regions. The analysis of Figures 3 and 4 shows that these regions have a higher percentage of private households when compared to other regions;

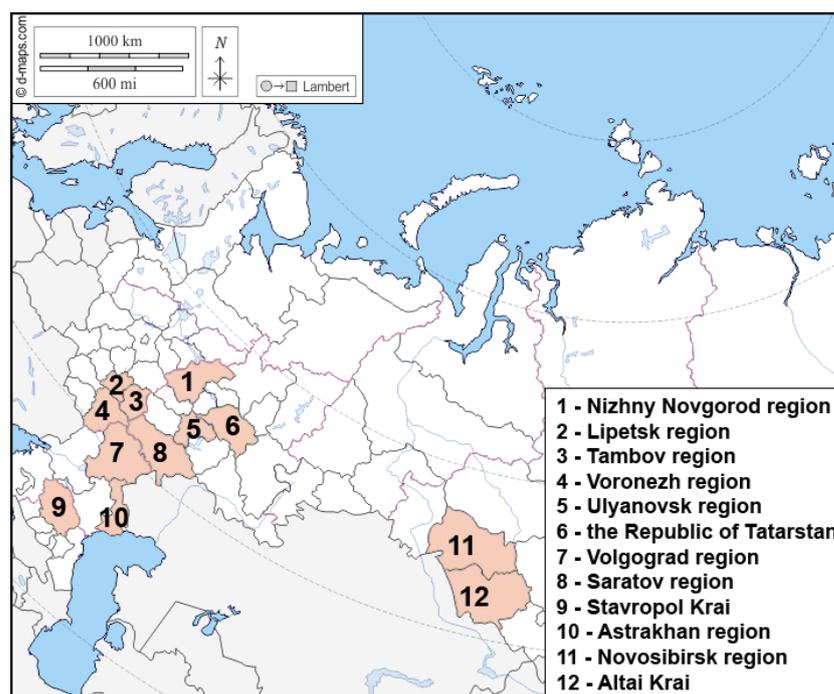


Figure 4. Regions of Russia where UAV flights are allowed or can be allowed.

- UAVs should be authorized to operate within the experimental legal framework and must bear state, registration, and civil aircraft registration marks in the Russian Federation;
- An external pilot of a UAV should have a temporary certificate as an external pilot of an agricultural unmanned aerial system obtained within an experimental legal framework and practical training in piloting. This training shall include, among other essential skills, the development of flight plans and the assessment of relevant meteorological and aeronautical conditions in the working area;
- The operator of the experimental legal framework is appointed by the designated governing body and is authorized to maintain a record of participants in the framework;
- There are restrictions on the scope of UAV operations. The use of digital technology-based UAVs is permitted for PPA application via aerial chemical operations;
- Restrictions apply to the flight path and flight plan of UAVs. The flight plan must comply with permitted overflight locations and be uploaded to the flight controller. UAVs may only be flown under the direct control of an external pilot, and automatic flight mode may only be used in emergency scenarios where the control line communication is lost;
- There are limitations on flight parameters, including a maximum true altitude ceiling of 15 m above the ground surface and a maximum ground speed of 16 m per second, which is equivalent to 57.6 km per hour;
- Flight operations are subject to certain restrictions. These include operating only within visual contact and a minimum distance of 5 km from airfield control points and 2 km from landing zones. It is also prohibited to fly over infrastructure elements such as highways, open trench pipelines, gas supply facilities, production sites, and power lines;
- A collision avoidance system must be installed to maintain a minimum distance of 2 m from obstacles when flying at maximum horizontal speed. In addition, when coming to a complete stop, the system should ensure that the UAV hovers at the stop altitude until externally instructed by the pilot;
- There are restrictions on the radio frequencies used by the radio-electronic elements integrated into the UAV.

Specific restrictions apply to

- Consumption rates of the PPA active ingredient and the number of treatments performed;
- Flight parameters during PPA field treatments. When applying PPA, UAV speeds should not exceed 25 km/h with a maximum wind speed of 14.4 km/h. Flight altitude should also remain below 2 m above the treated crop surface;
- PPA spraying equipment.

When treating crops with PPA, it is important to follow the guidelines of the Work Safety Regulations, which is the Russian analog of the Occupational Health and Safety Regulations [86]. These guidelines limit the daily working hours to a maximum of six hours and recommend working during the coolest hours of the morning and evening in hot seasons with wind speeds below 10.6 km/h. Aerosol treatments, including ULV treatments, should be performed at times when there is no natural light, such as in the evening, at night, or before sunrise.

A comparison between the listed regulatory requirements and the UAV operating modes discussed in Section 3 suggests that the implementation of optimal operating modes for UAVs is not hindered.

4.3. Adapting UAV Strategies to the Russian Market

According to research, the cost of unmanned aerial vehicles (UAVs) in Russian conditions is comparatively high due to specialized software. DroneDeploy [71], a well-known UAV software provider, offers access to the most comprehensive data repository of information collected by UAVs worldwide. Its mobile application enables automatic mapping and photography of DJI-branded UAV flights. The operation of unmanned aerial vehicles (UAVs) requires technical expertise in a variety of fields, including agronomy, aerodynamics, engineering, and legal regulations. Due to the limited availability of qualified professionals in these fields and the diversity of households using UAVs, several operational models have been created and are outlined in Table 11 [72].

Table 11. Unmanned aerial vehicle (UAV) usage models in agriculture [72].

Type of Usage	UAV	Software
Own UAV, external software	Purchased into the farmer’s property	Software as a service or integrated with UAV
UAV as a service	Purchased as a service from the operator	
Whole household economy as a service	All data and analysis for management decision making is provided as a subscription service	

Currently, the number of companies offering such services is limited to a list provided in [85] due to regulatory implications. The listed companies include BAS Consortium, AGRIMAX.AERO, INDUSTRIAL DRONES, Aeromax-Avia (South) and others.

The regions discussed in Section 4.2 preclude the standardization of specialized UAV software due to their different climatic zones and soil potential. Therefore, it is necessary to develop software for each type of terrain, taking into account the specific characteristics of the region’s climate.

4.4. Economic Impact of UAVs in Crop Production

We now analyze the economic aspects of using UAVs for crop production in the Russian environment.

According to the analysis of the Russian literature [70,89–92], it has been observed that traditional land-based and airborne equipment for pesticide and fertilizer application is superior to UAVs in terms of performance. In addition, the direct operating costs of traditional equipment are significantly lower. When comparing the final results of drones and conventional sprayers, it is important to consider additional factors such as economic feasibility, plant stress, seed characteristics of the crop, and the percentage of disease

and pest development [91]. These factors highlight the need for further research into the implementation of digital technologies in crop production.

The following sections aim to provide further explanation of the above comments, using the examples presented in [71,89–92].

4.4.1. Higher Operating Costs

According to Table 12 in [90], a comparison was made between conventional technology using a tractor and digital technology using a UAV for the cultivation of three cultivars of winter barley (Carrera, Versailles, and Agricultural) on thirteen 9 m × 4 m plots. The plots were flat and without any structures. According to Table 13 in [90], the cost estimates for the individual operations of barley cultivation, as well as the equipment used, are given. It should be noted that the field was preceded by winter rape.

Table 12. Cost estimation for the treatment of winter barley [90].

Indicator	With Ground Vehicles	With Unmanned Aerial Vehicle (UAV)
Productivity per 1 h shift, ha/h	12	3
Labor costs, man by hour/ha	0.24	0.99
Direct operating costs, RUB, including	573.09	8614.98
labor payment	69.47	6552
payment for fuel and oil materials	144.06	105
repair and maintenance	151.02	723.32
amortization charges	205.76	972.58
other direct costs	2.78	262.08
Specific capital investments, RUB/ha	1415.65	6575.56

Table 13. Cost of assessed treatment for winter barley [90].

Processing Type	Vehicles		Fertilizers and Plant Protection Agents (PPA)		
	Brand	Cost, Thousands of RUB	Fertilizer	Doses, L/ha	Cost of 1 L, RUB
Mineral fertilizers	UAV DJI Agras T10	1.076	Ammonium nitrate	98	20
	Tractor MTZ-1221	3.635			
	Amazone ZA-X perfect fertilizer spreader	216			
	Total:	1.996			
Herbicide treatment	UAV DJI Agras T10	1.076	Axial, 1 L/ha	7.5	3.0
	Tractor MTZ-80	0.990		200	
	Sprayer Amazone UF-901	1.006	Derby, 0.07 L/ha		15.684
	Total:	1.996			
Fungicide and insecticide treatment	UAV DJI Agras T10	1.076	Elatus Ria 0.5 L/ha	7.5	6.804
			Eforia 0.2 L/ha		5.674

The plants were subjected to differential treatment, and their status was evaluated using a UAV Phantom 4 Pro equipped with RGB cameras to generate a Normalized Difference Vegetation Index (NDVI) map. Harvesting was done with a TERRION 2010 combine harvester at predetermined dates. The yields of the cultivars Agricultural, Versailles, and Carrera were 11.4 t/ha, 11.0 t/ha, and 11.7 t/ha, respectively, with an average fertilizer dose of 100 kg/ha. According to the study in [90], the cultivar Versailles had an increase of 8.9% and the cultivar Carrera had an increase of 6.4% when using UAVs and the differentiated treatment. However, the cultivar Agricultural had a decrease of 1.8%.

Based on the findings of [90], it is more cost-effective to use ground equipment rather than farmer-owned UAVs for flat, level small area plots without buildings. The results of the experiment support this conclusion, showing an average yield increase of 3.6% with a 2% reduction in the amount of fertilizer required, at an additional investment of RUB 5159.91 thousand. Renting UAVs from specialized companies is a viable option for using them without incurring additional capital investment. This approach has already been successfully implemented on small farms in China [93].

4.4.2. Incorrect Type of PPA When Using UAVs

In [91], a comparison of similar technologies is presented, including a case study of incorrect PPA selection for UAV use. The case study uses the soybean cultivar Bingo as an example.

The following products were used as PPA at different stages of growth:

- Hermes MD (2 L/ha) and Kupazh VDG (0.008 L/ha) were applied at the weed germination and 1–3 leaf emergence stages;
- Geyser KKR (2 L/ha) and Kupazh VDG (0.008 L/ha) were applied at the 2–6 leaf emergence stage;
- Kinfos KE (0.4 L/ha) was applied in the 3–7 triple leaf phase of the crop;
- Vintage ME (1 L/ha) and Kinfos KE (0.4 L/ha) were applied from budding to the beginning of flowering;
- up to 10–20% Ultramag Potassium (3 L/ha) was applied at the stage of bean browning;
- Tongara BP (2 L/ha) was applied 7–10 days before harvest when 50–70% of the beans were browned.

Application rates were 4.5–10 L/ha when UAVs were used and 300 L/ha when ground machinery was used. Table 14 of [91] provides a comparative analysis of grain biochemical composition and soybean yield for the different treatments.

Table 14. Comparative analysis of soybean grain biochemical composition and yield with regard to treatments [91].

Technology	Yield, kg/ha		Actual Mass Moisture Content, %	Proteins, %	Oil Content, %	Weight of 1000 Seeds, g
	At Actual Humidity	At Standard Humidity				
Using UAV	3060	2750	20.9	33.4	23.4	183.3
Using ground vehicles	2540	2310	19.7	34.9	22.9	162.8

Based on the analysis of the data in Table 14, the authors conclude that despite the 440 kg/ha increase in soybean yield when the UAV was used, an increase in seed moisture and a decrease in the percentage of protein content in the seed were observed. The authors [89] suggest that the incorrect choice of a contact-type pesticide resulted in a low working fluid flow during UAV spraying, which may have prevented the pesticide from penetrating deep into the crop.

To overcome this problem, we believe it is recommended to reduce the UAV flight altitude, which should increase the PPA flow rate. This approach is demonstrated in the description of the vertical spray mode for corn crop treatment in Section 3.3.

4.4.3. Economic Efficiency of UAV Application Influenced by Land Use Coefficient

In our opinion, a more objective approach to evaluate the economic efficiency of UAV application in crop production is presented in [89]. The proposed method evaluates the economic efficiency based on the degree of land use, which is estimated by the Land Use Coefficient (LUC)

$$LUC = F_N / F_T, \tag{4}$$

where F_N represents the area of crops specifically dedicated to crops, while F_T includes the total area of the plot, including roads, structures, and buildings.

According to [89], there is a correlation between the cost of PPA treatment for rice and the LUC at which the use of UAVs for treatment becomes economically viable compared to ULVs. Figure 5a illustrates this relationship using data from [89], while Figure 5b clarifies the concept of critical LUC.

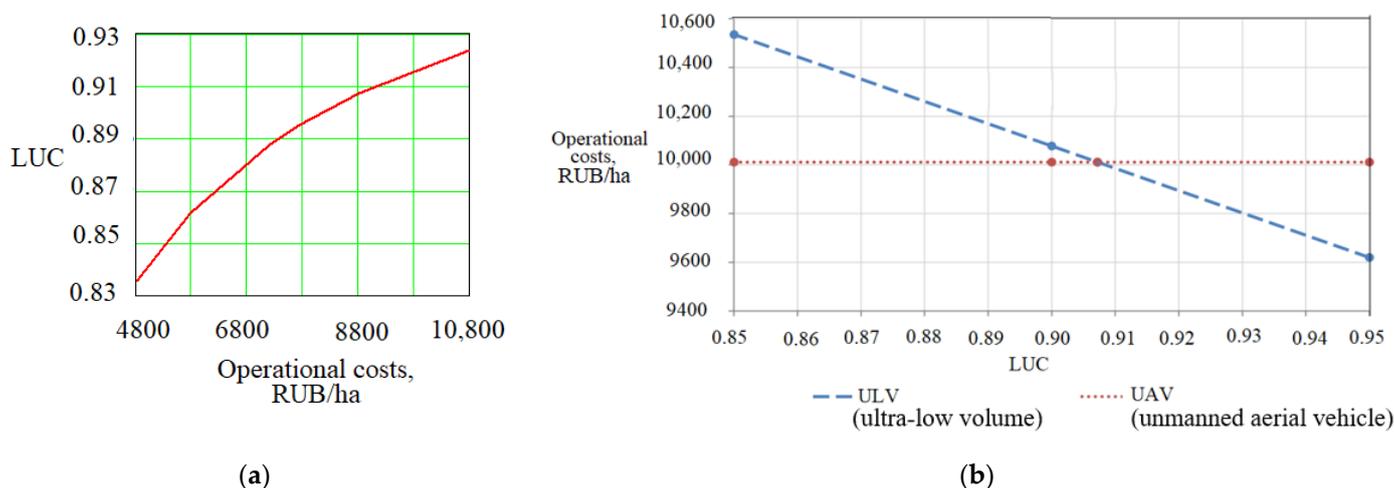


Figure 5. Influence of the value of 1 ha plant protection agent (PPA) treatment cost on the critical value of land use coefficient (LUC): (a) General dependence; (b) Explanation of the critical point concept.

For Figure 5b, it is assumed that the treatment cost for small aircraft use is 350 RUB/ha with a PPA application rate of 50–100 L/ha. For UAV use, the treatment cost is assumed to be 1100 RUB/ha with a PPA application rate of 5–10 L/ha. The cost of 1 L of herbicide is RUB 11,014. It is assumed that in both cases, the equipment is rented from a specialized company. The investment for the purchase of the equipment is included in the cost of crop treatment.

According to the analysis of Figure 5b, the use of UAVs for rice treatment is cost-effective compared to ULV only when the LUC value is below a certain critical value. This critical value corresponds to the point of intersection of the linear cost relationships for ULV and UAV application. The critical LUC value at which UAV use becomes economically inefficient depends on the cost of PPA treatment per hectare, as shown in Figure 5a.

Therefore, it can be concluded that the use of UAVs can be economically advantageous in areas with uneven terrain or inarable land, provided that the percentage of inarable land is around 17% or more, depending on the treatment cost. This conclusion is supported by the results presented in [10] regarding the use of UAVs in China. The study shows that UAVs are particularly effective in cultivating crop edges near roads, ravines, or technical buildings. This is supported by reference [93], which also confirms the effectiveness of UAVs in cultivating fields in mountainous areas.

4.4.4. Influence of the Length of the Treated Area and the Flight Characteristics of the UAV on the Cost of Using UAVs for Treatment

The cost of treating crops with agrochemicals, such as pesticides and mineral fertilizers, using UAVs is influenced by the technical characteristics of the flight. As shown in Section 3, the flight speed and altitude of the UAV affect the fluid flow. Figure 6 from [92] illustrates the dependence of UAV application costs on these technical characteristics.

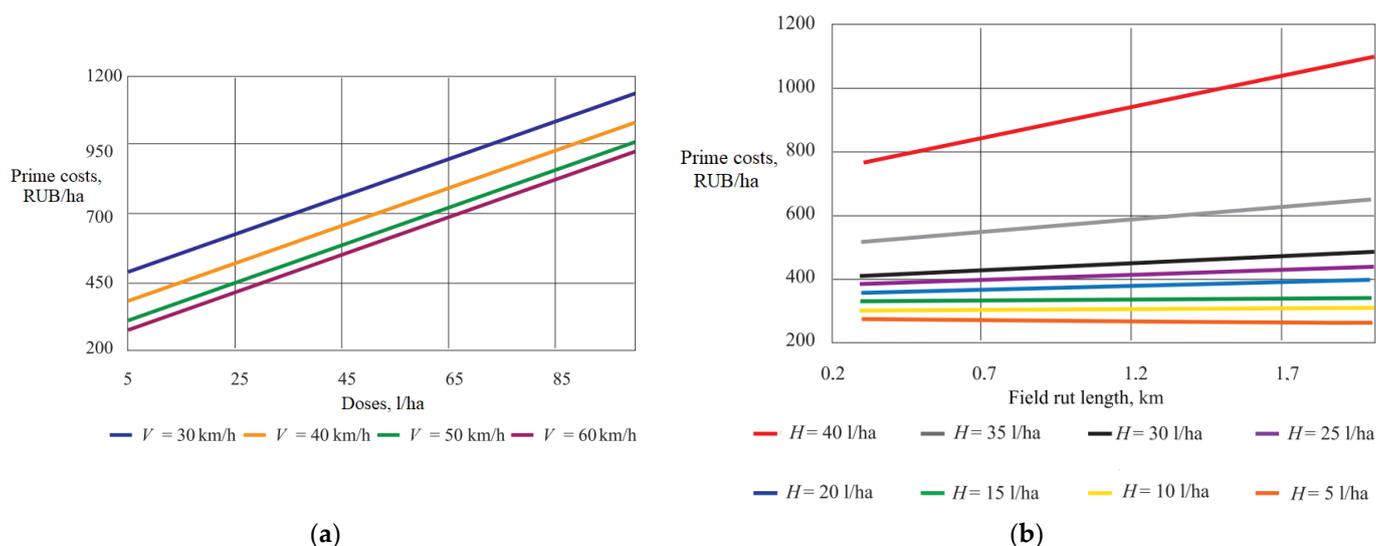


Figure 6. Influence of technical characteristics and agrochemical application rates on the cost of crop treatment with UAVs: (a) Influence of UAV operational flight speed and agrochemical application rate at the rut length of the cultivated field 1 km; (b) Influence of rut length and agrochemical application rate at the operational flight speed of 60 km/h [92].

The relationships shown in Figure 6 are based on the assumption that the UAV carries a 100 kg payload. The working fluids are filled at a distance of 0.2 km from the treatment area. The agrochemical application rates refer to pesticides (10–20 L/ha) and nitrogen fertilizers (30–100 L/ha). Analysis of the data presented in Figure 6a shows that increasing the UAV flight speed from 30 km/h to 60 km/h reduces the cost of agrochemical treatment. The decrease in spray rate is a result of the decrease in surface coverage as shown in Section 3 (Tables 9 and 10). The number of fluid refills is affected by the length of the rut and the rate of agrochemical consumption, which is limited by the size of the UAV tank. Therefore, increasing the length of the UAV route also increases the cost of treatment. In addition, the analysis of Figure 6b shows a lower limit for the field length, which is 200 m. As stated in the paper [93], the site area must be larger than 2 hectares.

4.5. SWOT Analysis of the Use of UAVs in Crop Production in Russia

The above results show that the use of UAVs in crop production in Russia has brought about changes in the economic, legal, agrarian, technical, and technological spheres. Therefore, it is recommended to conduct a SWOT analysis. Ref. [94] explains that SWOT analysis is a strategic planning and management technique used to identify and analyze internal strengths and weaknesses, as well as external opportunities and threats that shape current and future operations, and to aid in the development of strategic goals. The SWOT matrix is commonly used in business competition or project planning. The analysis helps individuals and organizations make informed decisions by evaluating internal and external factors that may affect their goals. It is also referred to as a situational assessment or analysis.

Let us summarize the results of the analysis of the current state of UAV implementation in Russian agriculture using the SWOT method, as shown in the example [95]. Figure 7 shows the results of the SWOT analysis of the use of UAVs in Russian crop production for field treatment with PPA and application of fertilizers.

Thus, the information presented in Figure 7 provides an answer to the final question posed in the Introduction section.

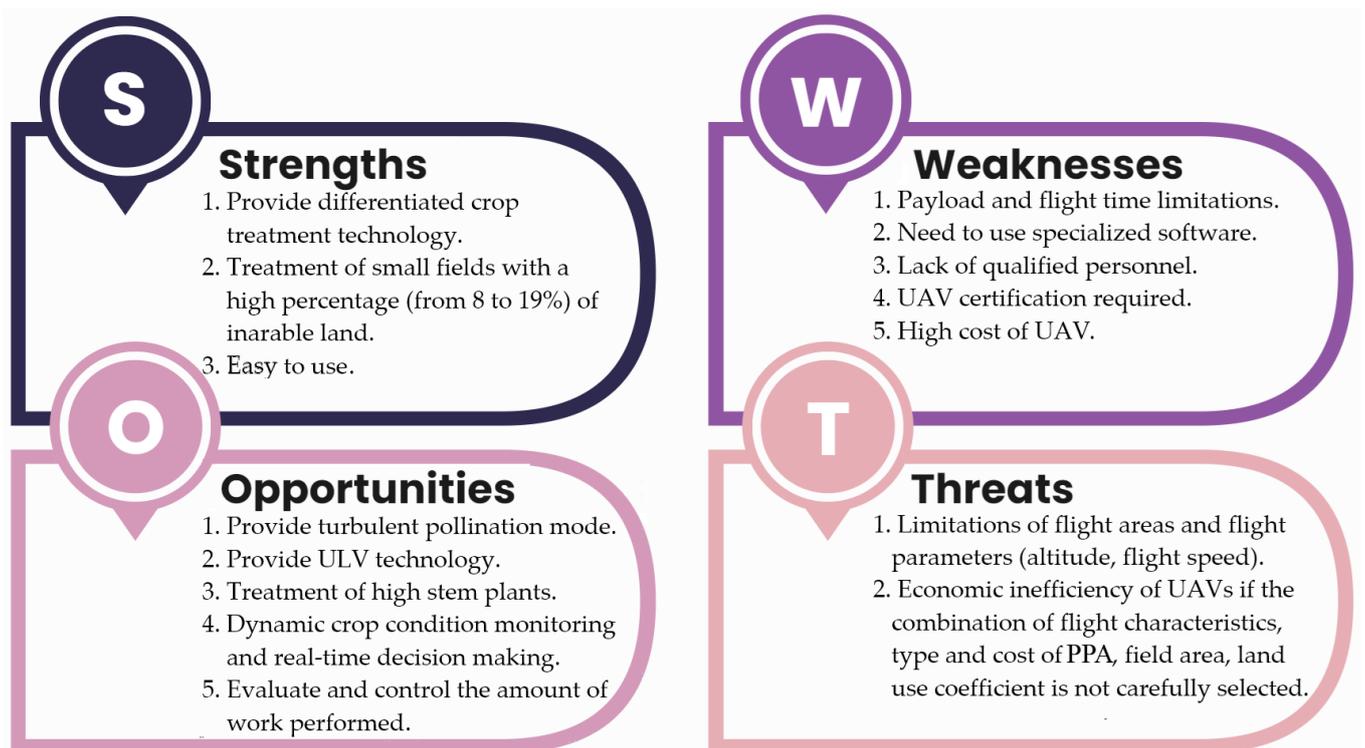


Figure 7. Results of SWOT analysis of unmanned aerial vehicle (UAV) application in Russian crop production for field treatment with agrochemicals.

5. Discussion

The analysis of the results presented in the review allows us to summarize that the aim of crop production development in Russia is to reach the level of grain production of 300 million tons per year by 2050. A potential tool for achieving this goal is the use of unmanned aerial vehicles (UAVs) for differentiated treatment of crops with pesticides, herbicides, and mineral fertilizers. Taking into account the distinctive peculiarities of the Russian economy and society, it is possible to identify the circumstances under which UAVs can be economically efficient in crop production in Russia. In particular, (1) the use of UAVs could potentially provide economic benefits for crop plots of irregular shape, larger than 2 hectares and containing between 9 and 19% of inarable land. In situations where these conditions are not met, government subsidies or services from specialized companies may be required. In our opinion, the use of UAVs will be economically justified in crop farms in mountainous areas of the North Caucasus Federal District and rice farms in the Southern Federal District. In particular, UAVs will be in demand as part of the state program announced in 2015 to combat the weed *Heracleum Sosnowskyi Manden*, which grows to a height of up to 3.2 m and has infested agricultural lands in the European part of Russia and the Far East [96]. (2) Traditional technologies may be more cost-effective for large acreage, as the capital cost of crop treatment using UAVs is more than four times higher than traditional methods. The main grain production areas in the plains, particularly the Volga FD, the Southern FD, and the Central FD, are able to meet these parameters. (3) It is important to agree on the flight parameters of the UAV, including speed, altitude, time, and when to switch to vertical spraying mode, as well as the technical characteristics of the on-board sprayer and the type of plant protection agent used. The literature review also shows that the UAV vertical spray mode is effective in tall maize crops, but ineffective in dense, stalked cereal crops. Contact insecticides show low efficacy due to low liquid consumption. Treating crops with UAV technology should be done at night because a small drop evaporates very quickly in the sun. When constructing a UAV route for crop treatment, it is necessary to provide for the possibility of bringing agrochemical containers for refueling.

6. Future Outlook and Perspectives

To promote the use of UAVs in crop production in Russia, the authors suggest the following possible directions. (1) To promote the purchase of agricultural UAVs in 2023, they have been included in the list of preferential loans and leasing. (2) It is recommended that personnel receive training in sciences related to agronomy, such as artificial intelligence, robotics, and mathematical methods. An example of this is the upcoming opening of training for agro-drone pilots at the Stavropol Agrarian State University in September 2024. (3) It is suggested that efforts be made to reduce the cost of agricultural UAVs and their software. Russia has recently announced the opening of 48 accredited research and production centers for the development and production of UAVs, with a budget of RUB 67.2 billion. (4) The certification procedure for UAVs will be simplified, drawing on the experience of other countries, such as India's IdeaForge company. (5) Ground equipment equipped with artificial intelligence (AI) systems could be considered for processing large areas of crops. The price of an AI-based system is RUB 1 million and it can be installed on any type of ground machinery. In 2023, the advantage of using a tractor with AI over conventional equipment will be RUB 2.6 million. This suggests that the system could potentially pay for itself in less than half a year. Such systems are especially effective in remote areas.

7. Conclusions

The review results confirmed that in order to achieve the Russian government's goal of significantly increasing grain exports, it is necessary to combine normal and intensive crop production agrotechnology with high (precision) agrotechnology. This review uses agrochemical crop treatment systems as an example to demonstrate how the selection of specific components of high (precision) agrotechnology, such as individual precision agriculture (PA), PA technology, and integrated PA techniques, as well as the system of crop treatment, whether it be unmanned aerial vehicles (UAVs) or ground equipment with artificial intelligence (AI) systems, depends on the size and shape of the cultivated area. The aim of this paper is to specify the economic efficiency conditions for the use of UAVs:

- The use of UAVs could potentially be economically efficient for plots with irregular shapes, larger than 2 ha, and containing between 9 and 19% of inarable land.
- It is important to agree on the flight parameters of the UAV, including speed, altitude, along with the type of on-board sprayer and type of agrochemical.
- If there is a lack of funds or expertise in related fields, the use of specialized companies is advisable.
- Ground machinery equipped with artificial intelligence (AI) systems is cost-effective for large acreages. The capital cost of crop treatment using UAVs is over four times higher than the cost of using traditional technologies. Equipping a tractor with an AI system can pay for itself in less than six months.

This review presents findings on the development of Russian crop production and suggests a list of regions where using UAVs for crop treatment with agrochemicals would be economically justified. It also provides materials and recommendations for the use of UAVs in crop treatment in Russia. However, the review does not cover all the issues related to the use of UAV in crop production.

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