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DEFINING FACTORS FOR THE EXPEDIENT USE OF AVIATION EQUIPMENT IN THE PROCESS OF GROWING AGRICULTURAL CROPS

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Aviation transport system in the agricultural sector has been examined in this study. The task addressed relates to determining the factors of expedient use of air transport at certain stages of the technological process of growing agricultural crops, depending on aircraft technical parameters.

The global experience in the development of agricultural aviation has been analyzed; analysis of the areas cultivated by land and air transport in Ukraine in 2013–2024 was performed. The negative impact of vehicles on the environment was revealed. Directions for improving environmental safety through the introduction of promising new technologies for environmental preservation have been determined.

Basic aviation means used to protect plants from harmful objects during the growing season were analyzed. The selection of aviation means for the implementation of crop protection measures should be carried out on the basis of a preliminary scientific and economic justification, taking into account the type and scope of work.

Ranges of the technological cycle duration and ranges of productivity by agricultural aviation activities based on the technical and operational characteristics of agricultural aviation means have been determined. The expediency of using aviation means under different standards of application of working substances has been clarified.

Under current conditions for precision agriculture, there is a need for wider use of air transport in the process of growing agricultural crops. An innovative tool for precision agriculture are unmanned aerial vehicles that help with field spraying, control and cartography of yield data, fertilization, as well as diagnosing crops for the presence of pests and diseases. That is why the market of unmanned technologies is rapidly evolving in Ukraine, which is a promising direction in the agricultural sector

Keywords: agricultural aircraft, agricultural drones, precision farming, environmental safety, sustainable development

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1. Introduction

An important area of civil aviation activities is the performance of various types of aviation work in many sectors of the national economy. Aviation work comprises those activities in which aircraft are used to provide specialized services in such industries as agriculture, construction, photography, topographic surveying, surveillance and patrolling, search and rescue, aerial advertising, etc. To increase the efficiency of the transport and technological process in agriculture, it is important to constantly improve it. This includes the rational use of ground and air vehicles depending on the type of crops grown and technological parameters.

The precision agriculture method defines the requirements for crops and soil by obtaining accurate remote sensing data. Precision agriculture is a method of regular agricultural management that makes it possible to solve the problems of agriculture: reducing resource use, costs, and environmental impact.

Under the conditions of a full-scale war, precision agriculture in Ukraine ceases to be just a tool for increasing yields and increasingly assumes the function of a technology for survival, adaptation, as well as maintaining production controllability in the agricultural sector. The war has radically changed the production environment: costs have increased, access to resources has deteriorated, some land has become dangerous or temporarily inaccessible, and production decisions have to be made faster and with much higher uncertainty. Agricultural enterprises in Ukraine face damage to infrastructure, logistical failures, limited access to resources and energy, land contamination by mines and unexploded ordnance, as well as labor shortages. While in peacetime the priority is often to maximize yields, during wartime cost minimization comes to the fore.

Under current conditions of precision agriculture [1], there is a need for greater use of air transport in the process of growing crops. Also, an important role in these conditions belongs to the introduction of innovative technologies for growing agricultural products using unmanned aerial vehicles. Unmanned aerial systems have significant potential for use in agriculture. They provide high accuracy in applying preparations, reduce risks for operators, and can be effectively used in difficult or inaccessible areas. At the same time, manned agricultural aviation remains more productive when performing work on large areas.

Therefore, it is a relevant task to carry out studies on the rational use of various types of aircraft at certain technological stages in the process of growing crops.

2. Literature review and problem statement

In recent years, the effectiveness of using unmanned aerial systems (UAV, UASS) in agriculture and their comparison with conventional manned agricultural aviation has been actively studied in the world scientific literature. Most attention of researchers focuses on such aspects as the effectiveness of plant protection products, the uniformity of the deposition of the working solution, pesticide drift, work performance, as well as the economic feasibility of using different types of aviation equipment.

In work [2], the authors compared the use of UAVs and manned aircraft according to three criteria such as spraying quality, expressed as coverage, pest control, expressed as effectiveness against target pests, and chemical residues. At the same time, such a factor as the duration of the technological cycle of UAVs and manned aircraft was not studied by the authors. A likely reason is their focus on the final result of treatment without taking into account the full production cycle of work.

In [3], the use of an unmanned helicopter for spraying vineyards using the tracer method was investigated. It was shown that for certain parameters of the working solution deposition, the results of the unmanned system are comparable to the results of manned agricultural aviation. However, the work did not determine for which areas, application rates, and organizational and technological conditions such a system is appropriate. This can be explained by the narrow focus of the study on a separate technological operation without considering it within the framework of the holistic process of growing crops.

An important area of research is the assessment of pesticide drift during aerial spraying. In [4], field measurements were conducted, which showed that under certain conditions, unmanned aviation systems can form a smaller drift of pesticides than conventional manned aircraft. This is explained by the lower flight altitude and the possibility of more precise control of spraying parameters. However, the study does not address the issue of choosing the type of aircraft in the technological process of growing crops, as it focuses on a single environmental indicator. A likely reason is the physical and technological focus of the work, within which production and operational parameters are not integrated into a single evaluation system.

References [5, 6] summarize the results of studies on the use of manned and unmanned agricultural aviation. It is shown that unmanned systems have advantages in local and precise treatments, while manned agricultural aviation is effective on large areas. At the same time, those papers do not contain quantitatively defined limits for the appropriate use of each type of equipment. Threshold values of the treatment area, application rate, cycle duration, and productivity, at which one type of aircraft has an advantage over another, have not been established. This may be due to the overview nature of the above work, in which the results of heterogeneous studies are summarized without building a single comparative model.

Regulatory and analytical studies also play an important role in shaping the current understanding of the prospects for the development of agricultural aviation. In particular, the OECD overview [7] reports a comprehensive analysis of scientific publications on the use of unmanned aerial systems for pesticide application. This document addresses the issues of safety, productivity, environmental impact, and risks of using UAVs compared to conventional aerial spraying methods. However, this document does not propose an approach to justifying the choice between unmanned and manned vehicles within a specific agro-technological process. The reason is the analytical and regulatory nature of the document, which does not provide for an engineering and calculation comparison of alternative technical solutions.

Important results have also been obtained in studies on modeling aerial spraying processes. For example, in [8], a model for predicting pesticide drift for unmanned aerial systems was built, which makes it possible to assess potential environmental pollution risks. The results confirm the possibility of using existing aerial spraying models to analyze the operation of unmanned systems. However, this model does not cover the duration of the technological cycle, productivity, refueling logistics and the organization of flight work. As a result, its application is insufficient to determine the feasibility of using a specific type of aircraft under real production conditions.

A separate area of research is related to the study of the influence of flight parameters on the effectiveness of spraying. In [9, 10], the influence of flight altitude, speed, nozzle type, and treatment modes on the uniformity of droplet deposition and pesticide drift was investigated. It was shown that optimization of flight parameters significantly affects the effectiveness of aerial application of preparations. At the same time, those studies do not provide an answer to the question of how the spraying parameters should be related to the technical and operational characteristics of a particular aircraft when choosing the type of aircraft for a certain technological operation. A likely reason is the orientation of such work on improving the spraying process, and not on the systematic justification of the choice of aircraft.

References [11–16] highlight the environmental aspects of the functioning of agricultural production and the impact of transport and technological systems on the state of the environment. They confirm the need to take into account the environmental component when assessing the effectiveness of crop cultivation technologies. At the same time, they lack a comparative assessment of the environmental feasibility of using different types of aircraft in the agricultural sector. This can be explained by the fact that in environmental studies, the transport and technological parameters of aviation systems are mostly not detailed.

Thus, our review of the literature [2–16] showed that available studies solve mainly individual partial problems: assessing the quality of spraying, biological efficiency, pesticide drift, the influence of flight parameters and individual environmental consequences. However, the scientific and applied task of determining the factors of the appropriate use of different types of aircraft in the process of growing crops, taking into account the combined effect of the technical and operational characteristics of aircraft, the duration of the technological cycle, the rates of application of working substances, the productivity of work and environmental restrictions, remains unsolved.

The main possible reason for the unsolved nature of this issue is the fragmentation of existing research, in which agro-biological, technical, production, and environmental indicators are considered in isolation, without integration into a single model of substantiation of the choice of the type of aviation equipment for specific conditions of the technological process. This is what predetermines the need for conducting research aimed at determining the factors of appropriate use of manned and unmanned aircraft depending on the technological operation, the rates of application of working substances, as well as aircraft technical parameters.

3. The aim and objectives of the study

The purpose of our study is to determine factors for the expedient use of different types of aviation equipment in the process of growing crops depending on the technological operations and aircraft technical parameters. This will provide an opportunity to obtain results for implementing modern aviation equipment in the technological process of growing crops.

To achieve the goal, the following tasks were set:

– to analyze the world experience of developing agricultural aviation and to analyze the cultivated areas in Ukraine;

– to investigate the influence of environmental safety factors in the process of growing crops;

– to determine the expediency of using aircraft with different volumes of input of working substances.

4. The study materials and method

The object of our study is the aviation transport system in the agricultural sector. The hypothesis of the study assumes that the expediency of using different types of aviation equipment in the process of growing crops is determined by the combined effect of the technical and operational parameters of aircraft, the duration of the technological cycle, and the rates of application of working substances.

The study assumes that the aircraft technical characteristics correspond to the specifications, and the implementation of technological operations takes place under typical production and agrometeorological conditions. Separate types of aircraft and scenarios for applying working substances were considered using the example of typical conditions for growing winter wheat in Ukraine.

To ensure comparability of the results, a simplification was adopted regarding the constancy of conditions for performing work, the absence of emergency downtime, disregarding the influence of the terrain, field configuration, the human factor, and changes in weather conditions within a separate technological cycle.

Methods of analysis and synthesis were used to determine the key conceptual provisions of scientific works on the use of air transport in the technological process of growing crops.

The statistical analysis method was used to study the areas treated by ground and air transport in 2013–2024.

Mathematical calculations were performed to determine the feasibility of using a certain type of aircraft for different volumes of working substance application.

The scenario modeling method was applied to test the calculation results using the example of typical production conditions for growing winter wheat in Ukraine. A practical case was formed for the conditions of an average agricultural enterprise, taking into account the area of crops, the rate of application of the working substance, the type of technological operation, as well as aircraft technical characteristics.

5. Results of the use of aviation equipment in the technological process of growing crops

5. 1. World experience in the development of agricultural aviation and analysis of cultivated areas in Ukraine

Civil aviation activities can be divided into air transportation and aviation work, or the use of aviation in the national economy. Modern solutions to increase the efficiency of the use of aviation in the national economy contribute to the development of not only the aviation industry and the country's transport system but many other industries, which leads to an increase in the growth rates of the national economy.

Review of refs. [17–19] showed that the world leaders in agricultural aviation are the following countries: America, Canada, Brazil, China.

Also, a high level of development of agricultural aviation is achieved in the countries of Europe, as well as Australia, Mexico, Argentina, Venezuela, and Ecuador. Ukraine has a moderate level of development of agricultural aviation at the global level but, having fertile lands and technological potential in the agricultural sector, it could reach a level of strong development. The development of agricultural aviation in countries around the world according to various characteristics is given in Table 1.

The use of aviation technique in the technological process of growing crops contributes to the implementation of resource-saving No-Till technologies and increased labor productivity. The introduction of the newest technologies for growing crops gives impetus to rapid changes in the agriculture of Ukraine. This trend is also observed in crop production, as a result of which the ratio of the volumes of various activities, including the work of agricultural aviation, is significantly changing.

In 2014–2020, as a result of the annexation of Crimea and military operations in the territory of part of the Donetsk, Luhansk, Zaporizhia, and Kherson oblasts of Ukraine, a continued reduction in the volumes of aerial processing of agricultural lands was observed. The dynamics of land processed by aviation technique over 2013–2024 were registered based on data from refs. [20, 21] and is shown in Fig. 1.

Over the period from 2021 to 2024, there was a rapid growth in agricultural areas treated by aviation. As more than 1,500 UAVs appeared in the agricultural market during that period, it can be argued that this growth was due to their use.

The relevance of using UAVs when performing aviation chemical activities is justified by the following factors:

– the fleet of conventional aircraft such as An-2, Mi-2, Ka-26, as noted earlier, is physically, morally, and economically obsolete;

– UAVs do not require airfields;

– UAVs within the framework of AHR fly at altitudes at which, according to the requirements of the Air Code, flights can be performed without legal regulation;

– a UAV is essentially an aerial robot, an accident or catastrophe of which does not pose a threat to human life since there is no contact of the crew with pesticides during the flight.

Even despite the war, Ukraine is a European breadbasket and has great potential to increase the production of wheat, barley, sunflower oil, sugar, and other agricultural products for export to the world market. The main agricultural crops of Ukraine are spring and winter wheat, corn, rye, barley, oats, sunflower, soybeans, sugar beet, potatoes, onions, garlic, nuts, grapes, rapeseed, cabbage, tomatoes, cucumbers, peppers, eggplants, watermelons, melons.

Thus, among the technological methods of growing crops, the most important component is the protection of plants from harmful organisms. The use of aviation in agricultural production allows for the timely and uniform application of agrochemicals, plant growth regulators, desiccants and defoliants, plant protection products, etc., and also prevents damage to crops that occurs during the use of ground equipment.

As a result, the increase in crop yields is on average up to 30% for cereals alone. For other crops – up to 25% of their average yield, which makes it possible to carry out agricultural aviation activities on a profitable basis and replenish the state budget [20].

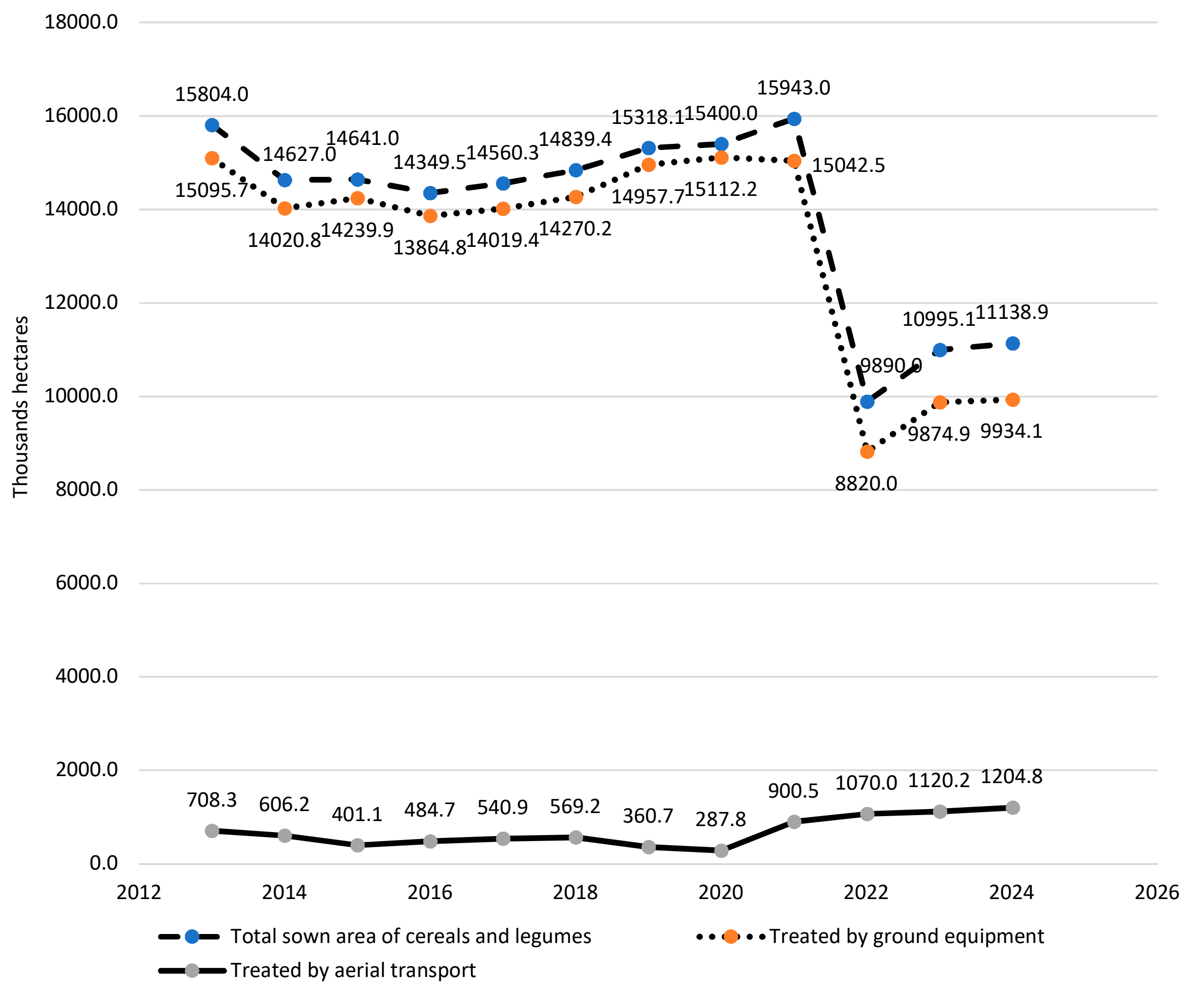

Fig. 1. Dynamics of areas processed by land and air transport, 2013–2024, thousand hectares
Note: compiled by authors based on refs. [20, 21]

Table 1

Development of agricultural aviation in countries around the world according to various characteristics

Criterion	Ukraine	European Union	USA	China	Latin America
Historical development	Active in the USSR, decline after 1990s	Limited to environmental policy	Development center since 1940s	Active development since 2010s	Development since the 1970s
Main type of aircraft	An-2, Mi-2, agricultural drones	Mainly drones	Air Tractor, Thrush	Agricultural drones	Air Tractor, Ipanema
The role of manned agricultural aviation	Limited	Minimal	Key	Decreasing	Important
The role of agricultural drones	Rapidly growing	Moderate implementation	Additional tool	Dominant	Growing
Main tasks	Spraying, desiccation, monitoring	Monitoring	Mass spraying	Precision farming	Aerochemical robots
Main crops	Wheat, corn, sunflower	Grains, grapes	Corn, soybeans	Rice, wheat	Soybean, sugarcane
Size of cultivated areas	Large fields	Medium farms	Very large farms	Medium fields	Very large plantations
Level of technology	Medium	High	Very high	Very high	High
Automation	Growing	High	High	Very high	Medium
Regulation	Government regulation	Strict legislation	FAA regulations	Government support	Moderate
Environmental restrictions	Medium	Very high	Average	Average	Medium
Investments in the industry	Medium	High	Very high	Very high	High
Scientific research	Development	Powerful universities	Leading research centers	Government programs	Development
Agricultural aviation infrastructure	Limited	Developed	Highly developed	Actively developing	Developed
Main development trend	Transition to drones	Precision farming	Combination of airplanes and drones	Mass use of UAVs	Aircraft + Drones

Note: compiled by authors based on [17–19].

5. 2. Influence of environmental safety factors in the process of growing crops

Protective measures are effective when they are carried out within the required agrotechnical terms and ensure maximum coverage of the target object with the required amount of the preparation, in a way that is safe for people and objects of the external environment. Therefore, the following factors are of great importance from the point of view of biological effectiveness: processing time, quality of coverage, consumption rate of the preparation and its environmental safety (Fig. 2).

The greatest effect in the fight against harmful objects can be achieved through the timely implementation of protective measures – within three, maximum five days. However, ensuring the implementation of these works within such a period using ground technical means is very difficult. In addition, the use of ground equipment when performing operations related to plant protection has certain limitations:

– at high soil moisture;

– when processing tall crops (corn, sunflower);

– while processing rapeseed before harvesting.

Under intensive technologies, fertilizing plants with solid mineral fertilizers was carried out in several stages throughout the entire period of their growth. The use of ground equipment for fertilizing could lead to an extension of the terms of operations, damage to plants by the wheels of technical equipment.

Agricultural aviation operations have made it possible to improve the quality of the harvest due to late feeding of plants without damaging them, increase the yield due to desiccation of plants and due to the treatment of rapeseed crops with special adhesives before harvesting. Also, an increase in the yield of agricultural crops by 10–15% is associated with the absence of technological tracks, timely and high-quality treatment of crops with chemical protection agents [20].

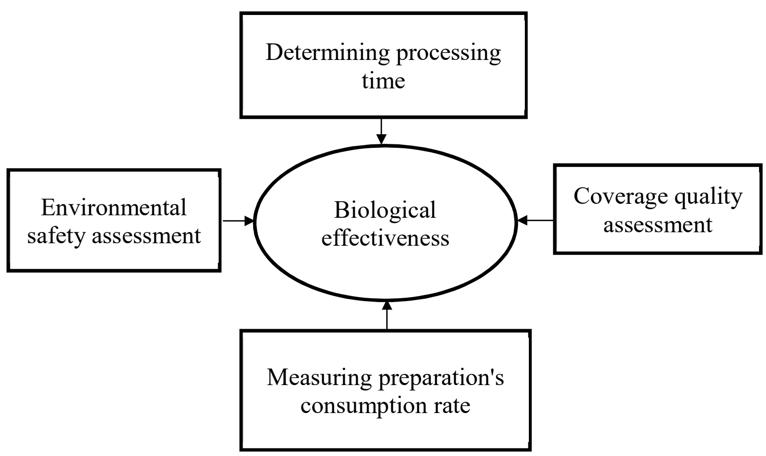

Fig. 2. Key factors influencing biological efficacy

When making decisions on aviation operations, the following main indicators were taken into account:

– ensuring the safety of aviation operations;

– performing the specified volumes of work with the specified quality and within the specified time (with the specified productivity);

– environmental indicators.

Environmental monitoring is particularly relevant when using conventional Soviet-era airplanes and helicopters, which, due to their wear and tear, emit significant amounts of carbon dioxide (CO_2), nitrogen oxides (NO_x), unburned hydrocarbons (CH), and particulate matter (PM). For example, the engines of An-2 or Mi-2 aircraft have increased specific fuel consumption, which directly affects the amount of harmful emissions per hectare of cultivated land.

Under current conditions, the priority task in Ukraine is not only to ensure food security but also maintain environmental safety. The use of aviation in agriculture, during various types of air operations, was accompanied by emissions into the atmosphere, which cause air, soil, and water pollution.

5. 3. Determining the feasibility of using an aircraft with different volumes of working substances

One of the main problems of the aviation industry in Ukraine is the wear and tear of the civil aircraft fleet, which requires renewal and improvement taking into account new achievements of the world aviation industry.

The modern aviation fleet of Ukraine, which performs aviation work in agriculture and forestry, consists of aircraft equipment of the Soviet era. These are, as a rule, An-2 aircraft, Mi-2 and Ka-26 helicopters, as well as ultralight NARP-1 and Kh-32 ("Bekas"), which have special equipment. However, Ka-26 helicopters were banned from flying over the territory of Ukraine due to the loss of human resources.

Aircraft, their special equipment and instruments were manufactured in 1970s–1980s. Thus, on the An-2 aircraft for scattering bulk fertilizers, An-2 pollinators, manufactured before 1979, are used; sprayer RTSh-1 of various modifications, sprinkler Sh-767000; for scattering Trichogramma – ART-2. The helicopter sprayer and pollinator Mi-2 are used on the Mi-2 helicopter. Ultralight aircraft NARP-1 and Kh-32 do not have equipment for scattering loose fertilizers, and rotating liquid sprayers are used for sprinkling.

The rapid evolution of technologies gives impetus to the development of the aviation market; more and more productive tools are offered with the possibility of their use in combination with new technologies. The situation with the existing fleet of aircraft performing work in agriculture and forestry in Ukraine is quite complicated. The existing fleet of agricultural aviation in Ukraine is outdated and has a number of shortcomings (high cost, non-compliance of flight-technical characteristics and consumer properties with modern requirements, etc.). It is necessary to update, improve, and revise the regulatory framework, as well as a large number of material and labor costs to maintain the airworthiness of aircraft. Therefore, the introduction of the Air Tractor 502XP is relevant.

The general view of the Air Tractor 502XP aircraft and the AeroDrone DR-60 unmanned aerial vehicle are shown in Fig. 3, 4, respectively.

The Air Tractor 502XP (Fig. 3) is an agricultural aircraft manufactured by the American company Air Tractor Inc. The aircraft is based on the AT-502A airframe and is equipped with a new Pratt Whitney PT6A-140AG engine, combined with a 4-blade Hartzell propeller, providing a power of 867 horsepower on the shaft. The Air Tractor 502XP is an excellent combination of power, stability, and productivity. It copes well with agricultural aviation work with a full load of 500 gallons (1893 liters) in mountainous and arid conditions. The technical characteristics of the aircraft, which are given in Table 2, are of great importance for the effective performance of aviation work.

Fig. 3. General view of Air Tractor 502XP

Fig. 4. General view of the AeroDrone DR-60 unmanned aerial vehicle [22]

Table 2

Air Tractor502XP specifications

Parameter	Data
Engine type	PW PT6A-140AG
Engine power	867 hp at 1900 rpm
Propellers	Hartzell HC-B4TN-3C/T10702NS
Take-off weight	4,754 kg
Landing weight	3,629 kg
Payload	2,209 kg
Payload	2,543 kg
Bunker capacity	1,893 l
Fuel capacity	885 l
Wingspan	15.84 m
Wing area	28.98 m^2
Main wheel size	29.00 * 11 – 10
Tail wheel size	5.00 * 5
Productivity	
Cruising speed at 2,438 m	269 km/h
Operating speed (typical)	193–225 km/h
Range at 2,438 m	1,075 km/h
Stall speed – flaps retracted	132 km/h at 3,629 kg
Stall speed – flaps extended	109 km/h at 3,629 kg
Stall speed for normal landing	85 km/h
Take-off distance	399 m at 4,754 kg

Analysis of Table 2 revealed that according to the declared technical characteristics of the Air Tractor 502XP aircraft, its bunker capacity (special equipment or chemical tank) is 1893 l. The An-2 aircraft has 1250 l (working volume), which is 643 l less than that of the Air Tractor 502XP aircraft. This provides the possibility of technological implementation of all ranges of agricultural aviation activities using different rates of fertilizer application from 6 to 250 l/ha.

To study the efficiency of agricultural aviation operations, aircraft that can compete in performing aviation activities were considered, namely NARP-1, An-2, and AeroDrone DR-60 (Fig. 4).

According to ref. [22] , the AeroDrone DR-60 UAV can spray using ultra-low volume technology, which does not require any water at all – that is, only the working agent is applied to the field in the required concentration without the use of water.

To briefly summarize ultra-low volume spraying – the nozzle of a conventional sprayer can form a droplet of 600–900 microns, the droplet falls on the plant and thus the chemical begins its action [22].

It is also worth adding that the AeroDrone DR-60 UAV and the ultralight NARP-1 UAV use the same agricultural machinery with a rate of application of substances of 0.5–10 l/ha. This rate is suitable for the use of ultra-small volume spraying but, unfortunately, is not suitable for the application of agrochemicals with high rates of application of working substances. In contrast, the An-2 and Air Tractor 502XP aircraft can perform all types of agricultural aviation work with a range of application of working substances from 10 to 250 l (kg)/ha.

To obtain a high yield, depending on the type of crop, it is necessary to perform certain technological operations using ground and air vehicles. The scheme of technological operations for obtaining a harvest of winter wheat is shown in Fig. 5.

According to ref. [23], obtaining a winter wheat yield of 60–80 quintals per hectare is ensured by three spring foliar nitrogen fertilizations and two pesticide treatments, namely:

– first fertilization after the resumption of vegetation in spring: 88 kg/ha or 30 kg/ha of active ingredient (ammonium nitrate);

– second fertilization at the beginning of the stem elongation phase: 147 kg/ha or 50 kg/ha of active ingredient (ammonium nitrate);

– third fertilization at the beginning of the earing phase: liquid fertilizers (urea) 100 l/ha of the mixture or 20 kg/ha of active ingredient;

– first pesticide treatment for protection against pests and diseases: 50 l/ha (can be combined with the 3rd stage);

– second treatment with pesticides to protect against pests and diseases: 25–50 l/ha.

The above technological operations can be performed using aircraft and ground equipment. However, ground sprayers require a technological track, which leads to crop losses. These losses depend on the working width of the unit.

The initial data for determining the feasibility of using an aircraft at different volumes of input of working substances are given in Table 3.

The duration ranges of the technological cycle of agricultural aviation operations are determined based on the technical and operational characteristics of the agricultural aircraft, such as the duration of engine start-up, loading of the aircraft chemical tanks with the working substance and taxiing to the start point. The technological cycle also includes the time required for take-off, turns, and landing; speed; aircraft characteristics; optimal loading and consumption of the working substance; width of the working grip, length of the runway and flight range of the aircraft from the runway of the airfield to agricultural land according to the following formula (1)

$$T_{cycle} = \frac{600 \cdot S_{rl}}{R_c \cdot W_{grip} \cdot V_w} + \frac{10 \cdot S_{rl} \cdot t_{turn}}{R_c \cdot W_{grip} \cdot L_{run}} + \frac{120 \cdot L_{reach}}{V_{reach}} + t_4 + t_5 + t_6, \quad (1)$$

where T_{cycle} – duration of technological cycle, min; S_{rl} – rational loading of chemical tanks of the aircraft with working substance, kg(l); R_c – consumption rate of working substance, kg(l)/ha; W_{grip} – width of working grip, m; V_w – working speed over the processing area, km/h; t_{turn} – turning time, min; L_{run} – length of run, km; L_{reach} – length of reach, km; V_{reach} – speed of the aircraft when reaching to/back of the processing area, km/h; t_4 – time for takeoff and landing, min; t_5 – time for engine start and taxiing to start, min; t_6 – taxiing time before loading with working substance, min; 600, 10, 120 – coefficients for converting the values of the indicators given in the formula to one of the corresponding units of measurement.

The productivity of aircraft per one production cycle is determined from formula (2)

$$P_{cycle} = \frac{60 \cdot S_{rl}}{R_c \cdot T_{cycle}}, \quad (2)$$

where P_{cycle} – productivity for one production cycle, ha/h.

The results of our calculations are entered in Table 4.

The technical characteristics of the special equipment show that all aircraft can operate with an application rate of up to 10 l/ha but only the An-2 aircraft and the Air Tractor 502XP aircraft can provide higher application rates. Analysis of the calculations of the duration of the technological cycle and productivity (Tables 3, 4) makes it possible to conclude that the use of the Air Tractor 502XP aircraft in agricultural aviation work will be more effective than the use of a comparative aircraft (Fig. 6), since the productivity of the Air Tractor 502XP aircraft is in the range of 5–200 l/ha and will be 147.28–65.78 ha/h, which is 17.93–22.02 ha more than that of the An-2 aircraft.

Table 3

Initial data for determining the feasibility of using an aircraft with different volumes of working substance injection

Indicator	NARP-1	AeroDrone DR 60	An-2	Air Tractor 502XP
Aircraft speed during flight to the treated area and back, km/h	110	–	165	250
Aircraft speed range (working), km/h	90–110	100	155–160	193–225
Time for aircraft turn, min.	1.1	0.7	1.1	0.7
Distance to the cultivated area, km	5	0	5	5
Length of the cultivated area, km	1.2	1.2	1.2	1.2
Time for takeoff and landing of the aircraft, min	1.6	1.1	1.6	1.5
Width of the working grip, m	25	20	30 (40)	30 (40)
Working substance input volume range, l (kg)/ha	0.5–10	0.5–10	10–200	10–200
Single loading of the aircraft bunker with working substance, l	120	40	1250	1893

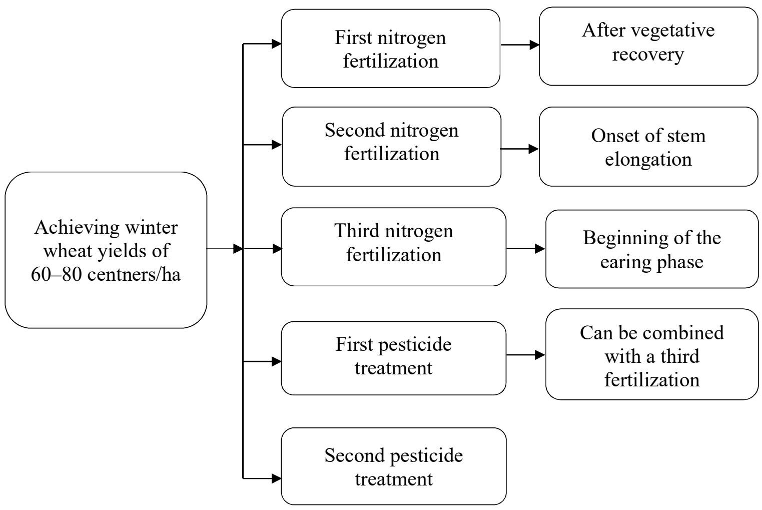

Fig. 5. Scheme of technological operations for obtaining a winter wheat yield of 60–80 centners/ha

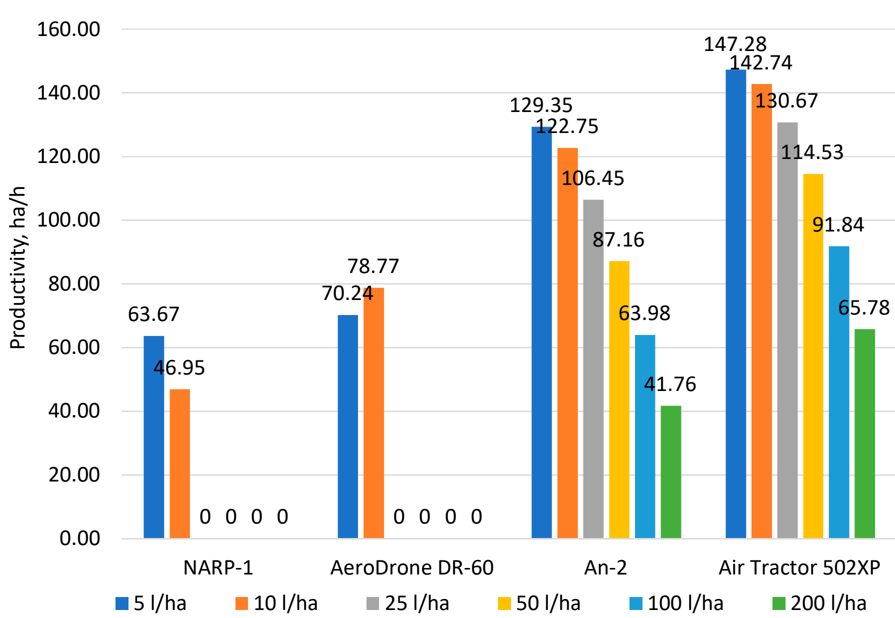

Fig. 6. Dynamics of agricultural aviation work productivity depending on the volume of working substance application, ha/h

Given the reduction in sown areas in Ukraine, the revival of aviation work in agriculture should take place using the latest technologies to improve quality and increase yields. This requires greater involvement of aviation equipment in the process of growing crops.

To model the practical scenario, a conditional average farm in the central part of Ukraine with a sown area of 1000 hectares, which is characterized by large-contour fields, was adopted. The processing of these lands has limited terms for performing technological operations and also requires the prompt application of plant protection products and liquid fertilizers in the spring-summer period.

The choice of this particular example is due to the fact that a similar structure of crops and technological operations is typical for most agricultural enterprises in Ukraine that specialize in growing grain crops. Such technology becomes particularly relevant under conditions of limited access to resources, fuel shortages, lack of equipment, and the need to minimize crop losses during wartime.

Within the framework of the practical case, one of the most common technological operations is considered – spraying winter wheat crops with a fungicide-insecticide mixture with an application rate of 50 l/ha. This operation is typical for the period of active vegetation, when ground application is often complicated due to plant height, soil moisture, or the risk of mechanical damage to crops.

According to the calculations carried out in our work, at an application rate of 50 l/ha, the productivity (Table 4):

– An-2 aircraft – 87.16 ha/h;

– Air Tractor 502XP aircraft – 114.53 ha/h.

The approximate net time for performing a technological operation for aerial processing of agricultural land is determined from the following formula (3)

$$t_{operation} = \frac{S}{P}, \qquad (3)$$

where $t_{operation}$ is the estimated net time of operation, h; S is the area to be processed, ha; P is the aircraft's productivity, ha/h.

Thus, for the processing of an area of 1000 ha, the estimated net time of the operation will be 11.47 h for the An-2 and 8.73 h for the Air Tractor 502XP.

Thus, the use of the Air Tractor 502XP aircraft makes it

Table 4

Results of calculating the duration of the technological cycle and the performance of aircraft at different volumes of working substance input

Indicator	NARP-1	AeroDrone-DR 60	An-2	Air Tractor 502XP
Working substance injection volume range	Duration of the technological cycle, min			
5 l/ha	22.61	6.83	115.96	154.23
10 l/ha	15.33	4.46	61.09	78.56
25 l/ha	–	–	28.18	34.76
50 l/ha	–	–	17.20	19.83
100 l/ha	–	–	11.72	12.37
200 l/ha	–	–	8.98	8.63
Working substance injection volume range	Processing productivity range, ha/h			
5 l/ha	63.67	70.24	129.35	147.28
10 l/ha	46.95	78.77	122.75	142.74
25 l/ha	–	–	106.45	130.67
50 l/ha	–	–	87.16	114.53
100 l/ha	–	–	63.98	91.84
200 l/ha	–	–	41.76	65.78

possible to reduce the duration of the technological operation by approximately 2.74 h, or almost 24%, compared to the use of the An-2 aircraft.

The practical significance of this result is that with a limited agrotechnical window, which in many cases is only 1–3 days, reducing the processing time directly affects the effectiveness of plant protection, the timeliness of the application of preparations and, accordingly, the final yield level.

In addition, in the case of using ground-based self-propelled sprayers, additional crop losses occur due to the formation of a technological track and mechanical damage to plants. Unlike ground-based equipment, aviation equipment allows for processing without contact with the crop, which is especially important in the tufting, earing, and late fertilization phases.

It should be noted separately that for local operations with ultra-low application rates (5–10 l/ha), in particular with point application of plant protection products, operational spraying of small areas, edge strips, problem areas or hard-to-reach areas, it is more expedient to use unmanned aerial vehicles, in particular the AeroDrone DR-60. According to the results of our calculations, at an application rate of 10 l/ha, its productivity is 78.77 ha/h, which makes it an effective tool for precision agriculture.

Thus, under the conditions of Ukrainian agricultural production, the expediency of using aviation equipment is determined not only by the technical characteristics of the aircraft but also by the scale of the farm, the type of crop, the rate of application of the working substance, the timing of work, and production risks. For large areas and high application rates, the most effective are piloted aircraft of the Air Tractor 502XP type, while for local and high-precision operations, the most appropriate is the use of agricultural drones.

As noted above, agricultural manned aircraft do not provide the necessary flight safety, and the industry cannot mass-produce them, as this requires large investments in the organization of their production. UAVs have proven to be a universal new tool for precision agriculture, helping farmers in spraying agricultural land, monitoring, and mapping yield data, applying fertilizers, as well as diagnosing crops for the presence of pests and diseases. Therefore, the use of unmanned aerial vehicles in the process of growing crops is a promising direction [22].

6. Discussion of results related to the appropriate use of air transport in the process of growing crops

The methods of analysis and synthesis allowed us to determine the key conceptual provisions of scientific and research works on the use of air transport in the technological process of growing crops. Modern solutions to increase the efficiency of the use of aviation in the national economy contribute to the development of not only the aviation industry and the country's transport system but also many other industries, which leads to an increase in the growth rates of the national economy.

When considering the development of agricultural aviation in the world [17–19], the leading countries in the use of aviation were identified, which are America, Canada, Brazil, and China. Countries with strong development of agricultural aviation include European countries, Russia, Australia, Mexico, Argentina, Venezuela, and Ecuador. Other countries have a moderate and different level of development of agricultural aviation.

It was determined that Ukraine has a moderate development of agricultural aviation at the global level but, having fertile lands and technological potential in the agricultural sector, it can reach the level of strong development. Grouping the development of agricultural aviation in countries of the world by various characteristics showed that the use of agricultural drones is growing rapidly in Ukraine while in China they dominate (Table 1). In the USA and Latin America, Air Tractor is most widely used; therefore, our paper considers the feasibility of using this particular aircraft.

Analysis of the dynamics of cultivated agricultural land areas for 2013–2024 revealed that over the period from 2021 to 2024, there was a rapid growth in agricultural areas cultivated by aviation (Fig. 1). It was found that during that period, more than 1,500 UAVs appeared on the agricultural market, thus it can be argued that this growth was due to their use.

The relevance of using UAVs in performing aviation chemical activities is currently justified by the following factors:

– the fleet of conventional aircraft such as An-2, Mi-2, Ka-26, as noted earlier, is physically, morally, and economically obsolete;

– UAVs do not need airfields;

– UAVs within the framework of AHR fly at altitudes at which, according to the requirements of the Air Code, flights can be performed without legal regulation;

– an UAV is essentially an aerial robot, an accident or catastrophe of which does not pose a threat to human life, since during the flight there is no contact of the crew with pesticides.

The use of aviation in agricultural production [20] allows for timely and uniform application of agrochemicals, plant growth regulators, desiccants and defoliants, plant protection products, etc., and also prevents damage to crops that occurs during the use of ground equipment. As a result, the increase in crop yields is on average up to 30% for cereals alone. For other crops – up to 25% of their average yield, which makes it possible to carry out agricultural aviation activities on a profitable basis and replenish the state budget.

A study of environmental safety factors (Fig. 2) in the process of growing crops showed that protective measures are effective when:

– they are carried out in the required agrotechnical terms;

– they provide maximum coverage of the target object with the required amount of the preparation;

– they are applied in a way that is safe for people and objects of the external environment.

Therefore, the following factors are of great importance from the point of view of biological effectiveness: processing time, coating quality, preparation consumption rate, and its environmental safety. It was found that environmental monitoring is especially relevant when using conventional Soviet-era airplanes and helicopters. Outdated aircraft, due to their wear and tear, emit a significant amount of carbon dioxide (CO_2), nitrogen oxides (NO_x), unburned hydrocarbons (CH), and particulate matter (PM). For example, the engines of An-2 or Mi-2 aircraft have an increased specific fuel consumption, which directly affects the volume of harmful emissions per hectare of cultivated land. Under modern conditions, the priority task of Ukraine is not only to ensure food security but also to maintain environmental safety. The use of aviation in agriculture, during various types of air operations, is accompanied by emissions into the atmosphere, which cause air, soil, and water pollution. Thus, it is proposed to replace old aircraft with more modern ones that almost do not emit harmful emissions.

The rapid evolution of technologies has given impetus to the development of the aviation work market; more and more productive tools have been proposed with the possibility of their use in combination with new technologies. Therefore, the situation with the existing fleet of aircraft performing work in agriculture and forestry in Ukraine is quite complicated. The existing fleet of agricultural aviation in Ukraine is outdated and has a number of shortcomings (high cost, inconsistency of flight-technical characteristics and consumer properties with modern requirements, etc.). It is necessary to update, improve, and revise the regulatory framework, as well as a large number of material and labor costs to maintain the airworthiness of aircraft. Therefore, the introduction of the Air Tractor 502XP is relevant (Fig. 3).

Among the technological methods of growing crops, the most important component is the protection of plants from harmful organisms. The use of aviation in agricultural production allows for the timely and uniform application of agrochemicals, plant growth regulators, desiccants and defoliants, plant protection products, etc., and also prevents damage to crops that occurs during the use of ground equipment.

To study the effectiveness of agricultural aviation, aircraft were considered that can compete in performing aviation work, namely NARP-1, An-2, and AeroDrone DR-60 (Fig. 4). Performing technological operations for growing crops is possible using aviation and ground equipment (Fig. 5). However, ground sprayers require a technological track, which leads to crop losses. These losses depend on the working width of the unit. Our paper provides initial data (Table 3) to determine the feasibility of using aircraft at different volumes of input of working substances.

The basis for constructing ways to solve the problem is the hypothesis of the dependence of the duration of the technological cycle and the productivity of aircraft at different volumes of working substance input. Mathematical calculations allowed us to determine the feasibility of using the aircraft at different volumes of working substance input.

Calculations of the duration of the technological cycle and the productivity of aircraft at different volumes of the introduction of working substances were performed. The technical characteristics of special equipment (Table 2) show that all aircraft can operate with an application rate of up to 10 l/ha, but only the An-2 aircraft and the Air Tractor 502XP aircraft can provide higher application rates.

Analysis of our calculations of the duration of the technological cycle and productivity (Table 4) makes it possible to conclude that the use of the Air Tractor 502XP aircraft in agricultural aviation work will be more effective than the use of a comparative aircraft. This is explained by the fact that the productivity of the Air Tractor 502XP aircraft is in the range of 5–200 l/ha and will be 147.28–65.78 ha/h, which is 17.93–22.02 ha more than that of the An-2 aircraft.

It was found that with the reduction of sown areas in Ukraine, the revival of aviation work in agriculture should occur using the latest technologies to improve the quality and increase the yield. This requires greater involvement of the newest aviation equipment in the process of growing crops.

The limitations of our study are the inability to more accurately determine the sown areas by regions of Ukraine as a result of military operations. This limits the determination of the required number of types of aviation equipment for processing agricultural land by region.

It was found that UAVs are a universal modern tool for precision agriculture, which help farmers in spraying agricultural land, monitor and map yield data, apply fertilizers, and diagnose crops for the presence of pests and diseases. Therefore, the use of unmanned aerial vehicles in the process of growing crops is a promising direction for further development of research in the post-war period.

7. Conclusions

1. The development of agricultural aviation in the world has been analyzed and the leading countries in the use of aviation were identified, which are America, Canada, Brazil, and China. Countries with strong development of agricultural aviation include European countries, Australia, Mexico, Argentina, Venezuela, and Ecuador. Other countries have moderate and different levels of development of agricultural aviation.

It was determined that Ukraine has moderate development of agricultural aviation at the global level but, having fertile lands and technological potential in the agricultural sector, it can reach the level of strong development. Grouping the development of agricultural aviation in countries of the world by various characteristics showed that the use of agricultural drones is growing rapidly in Ukraine while in China they dominate. In the USA and Latin America, Air Tractor is most widely used; therefore, our work considers the feasibility of using this particular aviation equipment.

An analysis of cultivated areas in Ukraine for 2013–2024 has been performed. The analysis revealed that during the period from 2021 to 2024, there was a rapid growth in agricultural areas processed by aviation. It was found that during that period, more than 1,500 UAVs appeared on the agricultural market, thus it can be argued that this growth was due to their use.

The relevance of the use of UAVs in performing aviation-chemical activities has been proven, which is justified by the following factors:

– the fleet of conventional aircraft such as An-2, Mi-2, Ka-26, as noted earlier, is physically, morally, and economically obsolete;

– UAVs do not need airfields; UAVs within the framework of AHR fly at altitudes at which, according to the requirements of the Air Code, flights can be performed without legal regulation;

– an UAV is essentially an aerial robot, an accident or catastrophe of which does not pose a threat to human life, since during the flight the crew does not come into contact with pesticides.

2. The influence of environmental safety factors in the process of growing crops has been studied. It was found that protective measures are effective when they are carried out within the required agrotechnical terms and ensure maximum coverage of the target object with the required amount of the preparation in a way that is safe for people and objects of the external environment. Therefore, the following factors are of great importance from the point of view of biological effectiveness: processing time, coating quality, preparation consumption rate, and its environmental safety. It was found that environmental monitoring is especially relevant when using conventional Soviet-era airplanes and helicopters. These aircraft emit a significant amount of carbon dioxide (CO_2), nitrogen oxides (NO_x), unburned hydrocarbons (CH), and particulate matter (PM) due to their wear. For example, the engines of An-2 or Mi-2 aircraft have an in-

creased specific fuel consumption, which directly affects the volume of harmful emissions per hectare of cultivated land. Under conditions of environmental pressure on the territory of Ukraine, the introduction of new environmentally friendly technologies is of particular importance. Additionally, switching to ultra-low volume (ULV) spraying using drones such as the AeroDrone DR-60 ensures minimal chemical impact on the environment, reduces water consumption for processing, and decreases the risk of secondary pollution. This is especially important in regions with limited access to clean water.

3. The feasibility of using the aircraft at different volumes of working substance introduction has been determined. Aircraft that can compete in performing aviation work were considered, namely: NARP-1, An-2, and AeroDrone DR-60.

Calculations were performed of the duration of the technological cycle and the productivity of aircraft at different volumes of working substance introduction. The technical characteristics of special equipment showed that all aircraft can operate with an application rate of up to 10 l/ha, but only the An-2 aircraft and the Air Tractor 502XP aircraft can provide higher application rates.

Practical testing of our results using the example of typical conditions for growing winter wheat in Ukraine showed that at an application rate of 50 l/ha, the productivity of the Air Tractor 502XP aircraft is 114.53 ha/h, which exceeds the indicator of the An-2 aircraft (87.16 ha/h). For a conventional farm with an area of 1000 ha, this makes it possible to reduce the duration of the technological operation by approximately 2.74 hours, which is of significant importance within the limited agrotechnical terms.

It was established that for large areas and medium and high application rates, the most appropriate is the use of piloted aviation equipment, in particular the Air Tractor 502XP, while for local, operational, and high-precision processing with a low application rate, the use of agricultural drones, in particular the AeroDrone DR-60, is more effective. This confirms the prospects for the differentiated use of aviation equipment under the conditions of modern precision agriculture in Ukraine.

It was found that with the reduction of sown areas in Ukraine, the revival of aviation work in agriculture should occur using the latest technologies to improve quality and increase yields. This requires greater involvement of the newest aviation equipment in the process of growing crops.

It was found that UAVs are a universal new tool for precision agriculture, which help farmers in spraying agricultural land, monitor and map yield data, apply fertilizers and diagnose crops for the presence of pests and diseases. Therefore, the use of unmanned aerial vehicles in the process of growing crops is a promising direction. The Ukrainian market of unmanned technologies is still at the initial stage of development but in recent years it can be said with confidence that the demand is there, and it is growing.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

All data are available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they used artificial intelligence technologies GPT-5.4 Thinking, with which Fig. 1 was generated based on the data from Table 1. The results generated by AI tools were verified by the authors by comparing Fig. 1 with Table 1. The Fig. 1 was drawn to visually display the data in Table 1.

Authors' contributions

Iryna Vysotska – Conceptualization, Methodology, Investigation, Writing – original draft, Writing – review & editing, Visualization, Supervision; **Svitlana Pron –** Methodology, Investigation, Writing – original draft, Supervision; **Iryna Herasymenko –** Methodology, Investigation, Writing – original draft, Supervision; **Oleksandr Pron –** Validation, Investigation, Writing – review & editing, Visualization; **Oleksandr Yeroshenko –** Validation, Investigation; **Fedir Vysotskyi –** Investigation, Formal analysis, Visualization.

References

1. Sanyaolu, M., Sadowski, A. (2024). The Role of Precision Agriculture Technologies in Enhancing Sustainable Agriculture. Sustainability, 16 (15), 6668. https://doi.org/10.3390/su16156668
2. Li, X., Giles, D. K., Andaloro, J. T., Long, R., Lang, E. B., Watson, L. J., Qandah, I. (2021). Comparison of UAV and fixed-wing aerial application for alfalfa insect pest control: evaluating efficacy, residues, and spray quality. Pest Management Science, 77 (11), 4980–4992. https://doi.org/10.1002/ps.6540
3. Giles, D., Billing, R. (2015). Deployment and performance of a UAV for crop spraying. Chemical Engineering Transactions, 44, 307–312. https://doi.org/10.3303/CET1544052
4. Wang, C., Zeng, A., He, X., Song, J., Herbst, A., Gao, W. (2020). Spray drift characteristics test of unmanned aerial vehicle spray unit under wind tunnel conditions. International Journal of Agricultural and Biological Engineering, 13 (3), 13–21. https://doi.org/10.25165/j.ijabe.20201303.5716
5. Delavarpour, N., Koparan, C., Zhang, Y., Steele, D. D., Betitame, K., Bajwa, S. G., Sun, X. (2023). A Review of the Current Unmanned Aerial Vehicle Sprayer Applications in Precision Agriculture. Journal of the ASABE, 66 (3), 703–721. https://doi.org/10.13031/ja.15128

6. Talaeizadeh, A., Sharifi, I., Alasty, A., Ghatrehsamani, S. (2025). Agricultural spraying drones: A comprehensive review. Smart Agricultural Technology, 12, 101519. https://doi.org/10.1016/j.atech.2025.101519
7. State of the knowledge literature review on unmanned aerial spray systems in agriculture (2021). OECD. Available at: https://www.oecd.org/content/dam/oecd/en/publications/reports/2021/04/report-on-the-state-of-the-knowledge-literature-review-on-unmanned-aerial-spray-systems-in-agriculture_ee9be37f/9240f8eb-en.pdf
8. Castro-Tanzi, S., Winchell, M., Tang, Z., Teske, M. E., Whitehouse, G. R., Fritz, B., Martin, D. (2025). Validation of the spray drift modeling software AGDISPpro applied to remotely piloted aerial application systems. Science of The Total Environment, 966, 178725. https://doi.org/10.1016/j.scitotenv.2025.178725
9. Byers, C., Virk, S., Rains, G., Li, S. (2024). Spray deposition and uniformity assessment of unmanned aerial application systems (UAAS) at varying operational parameters. Frontiers in Agronomy, 6. https://doi.org/10.3389/fagro.2024.1418623
10. Psiroukis, V., Kasimati, A., Nychas, K., Anastasiou, E., Balafoutis, A., Fountas, S. (2026). Comparison of spray drift between spraying drone and conventional airblast sprayer in vineyards. Smart Agricultural Technology, 13, 101741. https://doi.org/10.1016/j.atech.2025.101741
11. Burliai, A. P., Burliai, O. L., Nepochatenko, O. A. (2018). The influence of activity of agricultural enterprises on the environmental environment. Naukovyi visnyk Uzhhorodskoho natsionalnoho universytetu, 20, 64–69. Available at: http://www.visnyk-econom.uzhnu.uz.ua/archive/20_1_2018ua/16.pdf
12. Normatyvno-pravove zabezpechennia okhorony atmosfernoho povitria (2022). Available at: https://dei.gov.ua/post/2321
13. Za ostanni dva roky Kyiv vybuduvav naibilshu v Ukraini systemu monitorynhu yakosti povitria (+foto, zvit). Available at: https://kyivcity.gov.ua/news/za_ostanni_dva_roki_kiv_vibuduvav_naybilshu_v_ukrani_sistemu_monitoringu_yakosti_povitrya/
14. Yakist atmosfernoho povitria v Ukraini do i pid chas povnomasshtabnoho vtorhnennia (2023). Kyiv. Available at: https://www.savednipro.org/wp-content/uploads/2023/10/zvit_doslidzhennya_101723.pdf
15. Zaporozhets, A., Babak, V., Isaienko, V., Babikova, K. (2020). Analysis of the Air Pollution Monitoring System in Ukraine. Systems, Decision and Control in Energy I, 85–110. https://doi.org/10.1007/978-3-030-48583-2_6
16. Radiation and Smog Alarm. Nastanovy ta pryntsypy opovishchennia naselennia pro yakist povitria, radiatsiinu ta khimichnu nebezpeku (2022). Praha - Ivano-Frankivsk: Arnika, 58. Available at: https://cleanair.org.ua/wp-content/uploads/2022/12/cleanair.org.ua-radiation-and-smog-alarm-uaqi-radiation-and-smog-alarm-2022-1.pdf
17. Agricultural Drone Industry Insight Report. DJI. Available at: https://www1.djicdn.com/cms_uploads/ckeditor/attachments/9171/03e81f9a23cf4df447b66c91c43d929a.pdf
18. China revises aviation law to regulate drones, tighten safety rules. Reuters. Available at: https://www.reuters.com/world/asia-pacific/china-revises-aviation-law-regulate-drones-tighten-safety-rules-2025-12-27/
19. International Code of Conduct on Pesticide Management. Guidance for aerial application of pesticides. https://doi.org/10.4060/cc8321en
20. Pron, S., Soloviova, O., Herasymenko, I., Borets, I. (2020). Modeling of the transport and production complex in the growing of agricultural crops, taking into account the aviation component. Eastern-European Journal of Enterprise Technologies, 2 (3 (104)), 30–39. https://doi.org/10.15587/1729-4061.2020.198742
21. Vysotska, I., Vysotska, M., Soloviova, O. (2025). Implementation of innovative technologies for growing agricultural crops using unmanned aerial vehicles. International Sustainable Transportation Symposium (ISTRAS'25). Baku, 53. Available at: https://istras.org/wp-content/uploads/2025/11/ISTRAS-Abstract-Book_final.pdf
22. 100 hektar za hodynu roboty - Ukrainska rozrobka AeroDrone DR60 pidkoriuie rynok aerodroniv. Available at: https://www.agroblog.com.ua/post/100-gektar-za-godinu-roboti--ukrainska-rozrobka-aerodrone-dr60-pidkoryuye-rinok-aerodroniv
23. Dobryva dlia ozymoi pshenytsi – etapy i stroky vnesennia dobryv i yikh vydy. Available at: https://uapg.ua/blog/dobriva-dlya-ozimoi-pshenici/