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Environmental benefits of agricultural aviation development

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Currently, there has been an almost complete reduction in traditional agricultural aviation work in Europe. This is due to the increasing efficiency of groundwork and the requirements for environmental protection during the use of plant protection products. The article presents issues related to the development of agricultural aviation and precision agriculture, which may contribute to the return of agricultural work to flying objects. Examples of manned and unmanned aerial vehicles (UAV) are presented, and the environmental impact of agricultural work using manned and unmanned aerial vehicles is estimated based on literature data. It turns out that thanks to modern technology, it is possible to reduce the emission of most exhaust components while meeting the requirements for the use of plant protection products. Compared to manned aircraft, using an unmanned aerial vehicle reduces CO_2, CO and NO_x emissions by over 80%, while increasing SO_2 emissions by approx. 15%.

Key words: *UAV, agricultural aviation, precision agriculture, aircraft, emission*

1. Introduction

Agroaviation is a branch of aviation that deals with performing agricultural operations from the air. Aircraft tasks include field spraying and fertilization [2, 35]. In addition, agroaviation equipment is used in forestry, among others, for extinguishing fires [2]. The beginnings of this branch of aviation date back to the early years of the 20th century. At that time, an attempt was made to use aircraft to spray pesticides as part of pest control [2, 35]. After World War II, agroaviation services flourished in the world. The first aircraft used in this aviation branch were military aircraft equipped with dusting devices capable of performing fertilization or pest control operations – spraying. In Poland, such activities began to be undertaken around 1925. Modified bomber aircraft were used for these purposes, and after World War II, CSS-13 aircraft were first used, and later, larger An-2 aircraft were used.

The best period of Polish agricultural aviation fell on the 1970s and 1980s. At that time, Poland, as a member of the CMEA (Council for Mutual Economic Assistance), specialized in the production of agricultural aircraft and helicopters. These aircraft were appreciated in Poland and abroad, and agricultural aviation tasks were also carried out in Africa, Asia and other parts of Europe [2, 12, 38]. It should be noted that this type of aviation is dangerous because the flight should be performed at very low altitudes – just below the plants, sometimes touching them (Fig. 1) [2, 27].

Fig. 1. Kruk Turbo over corn field at very low altitude to make the spraying effective [2]

Systemic changes, the liquidation of State Agricultural Farms in Poland and the import of modern tractors and agricultural equipment from Western countries ended the development of Polish agricultural aviation in its previous form [2, 35, 38]. The development and decline of the use of agricultural aviation in the years 1950–2000 are shown in Fig. 2. The manned agricultural aircrafts are also used to fight forest fires because a large amount of water can be precisely dropped from the air onto the front of a fire [2, 12, 24, 25].

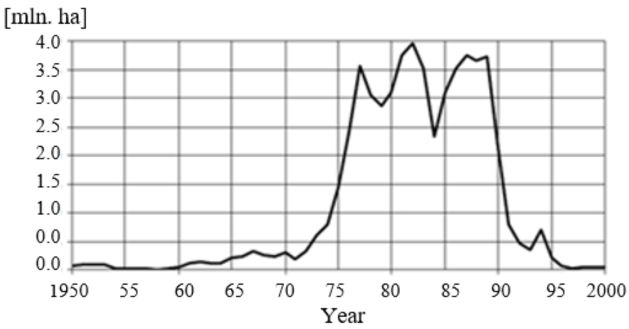

Fig. 2. The treatment area covered by agricultural aviation in Poland [41]

The limitations of agro-aviation include the unit costs of performing agrotechnical treatments, especially in small fields, and activities related to environmental protection. In the case of legal conditions, one of the applicable acts is Directive 2009/128/EC of the European Parliament and of the Council from 21 October 2009, establishing a framework for Community action to achieve the sustainable use of pesticides [19, 26]. Despite the limitations related to the intensification of activities to protect nature, agro-aviation is still present in countries where crops are grown on large-area farms, including the USA, Brazil, Australia and New Zealand [2].

The appearance of unmanned aerial vehicles (UAVs) on a large scale in the 21st century has contributed to the fact that these machines are used not only for hobby purposes but also for commercial applications. Unmanned aerial vehicles can have various applications due to the wide range of possible configurations, such as multi-rotors or fixed-wing aircraft. Therefore, unmanned aerial vehicles have begun to provide a wide range of services, such as blood transport between hospitals in Warsaw, Sochaczew and Pułtusk [2] and border monitoring in the service of the Border Guard. The police use unmanned aerial vehicles to monitor roads to detect violations of road traffic regulations and to monitor streets. The use of unmanned aerial vehicles in the service of the Fire Department is becoming more and more common – their flight and transport properties allow the installation of several sensors to detect smoke or other signs of fire [49].

One of the branches that use unmanned aerial vehicles is agro-aviation. A noticeable increase in interest in such use of UAVs has been noticeable for several years. Designs have been created to carry special types of cameras or fly with liquid tanks for fertilization or spraying and perform other functions. Due to legislative restrictions regarding spraying and lifting capacity, unmanned aerial vehicles are most often used in so-called precision agriculture [47, 51].

The aim of this study is to present how agricultural aviation has changed over the years, including changes in aircraft and methods, which together lead to a new type of agriculture called precision agriculture. In addition, the authors attempted to estimate the emission of agricultural work carried out using a manned and unmanned aerial vehicle. This comparison is to reflect the changes that have occurred in aviation with the replacement of traditional agriculture with precision agriculture. For the purpose of the analysis, the authors based their analysis on available literature data.

2. Traditional and precision agricultural aviation

The greatest advantage of agricultural aviation over ground agriculture was the high efficiency of fieldwork, which according to some sources, is even about 170–200 ha/h, while the maximum efficiency of agricultural operations using manned aircraft is about 300 ha/h [40]. For comparison, the efficiency of spreading bulk fertilizers using an agricultural tractor with a spreader with a working width of 15 m is 4 ha/h [29]. Another advantage of agricultural aviation is the lack of compaction of the ground on which the cultivated plants grow.

It should be noted, however, that performing agricultural aviation treatments is very expensive because of the need to use expensive equipment, such as aeroplanes, qualified personnel, and many additional activities, which takes time and money [31]:

1. loading of the working medium (pesticides, etc.) into the tank of the agricultural aircraft
2. taxiing for take-off
3. take-off
4. flight to the treatment area
5. working flight over the treatment area with turns at the ends of the field
6. if other fields are treated during one flight, steps 4 and 5 are repeated
7. flight to the landing area
8. landing
9. taxiing to the reloading site or to the parking place.

It is crucial that the airfield site should be as close as possible to the treatment area because the distance affects the amount of fuel consumed by the plane and the time of the operation. It consequently influences the procedure's costs and the environmental impact (Fig. 3).

Analyses that can be found in the literature conclude that depending on the dose of plant protection products, traditional agricultural aviation treatments are profitable for fields larger than 20 ha [39].

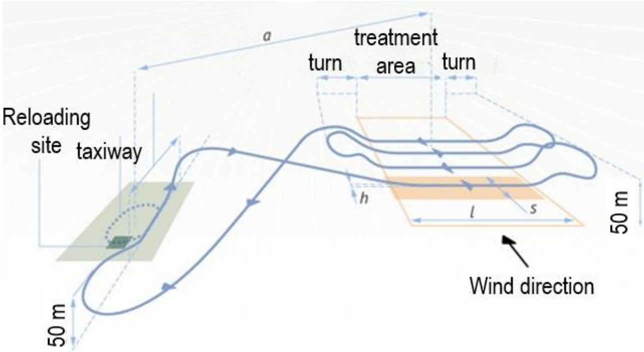

Fig. 3. Flight profile during an agroaviation procedure [2]

In the field of agro-aviation, an industry standard was also created, which defined the basic concepts related to this type of agro-technics, including the description and specification of equipment, and also presented several formulas facilitating the characterization of agroaviation treatments in numerical form. In addition, the activities that make up the work cycle were specified and certainly also affect the time and costs of the treatments performed [31].

Recently, there has been a reduction in the scope of agricultural aviation operations, which is related to more efficient machines for ground-based agricultural work and restrictions resulting from regulations, the main regulation in this respect being Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009.

The regulations regarding the use of plant protection products in agricultural aviation treatments include the following statements:

- "plant protection products may be applied using agricultural aviation equipment if the control of harmful organisms is not possible using ground equipment or the application of plant protection products using agricultural aviation equipment poses a lower risk to human or animal health or to the environment than using ground equipment
- it is prohibited to use herbicides, desiccants and plant protection products that pose a risk to human or animal health using agricultural aviation equipment" [20, 26].

For this reason, emphasis is placed on the development of precision agriculture, in which each plant is considered individually. The aim is to ensure that each cultivated plant has the best possible development conditions. Thanks to this approach, the use of plant protection products is significantly reduced, which is an important step towards the development of sustainable agriculture [21]. In addition to lower environmental costs, the costs of spraying are reduced while maintaining the highest possible quality of crops [11]. For example, in rapeseed cultivation, the costs of fertilization and plant protection constitute approx. 56% of the total cultivation costs (Fig. 4).

Among the technologies used in precision agriculture are unmanned aerial vehicles. Drones are primarily used to collect information about crops. Such field monitoring saves time, energy and resources because, thanks to the information obtained, it is possible to indicate parts of the field that require fertilization, spraying or harvesting [8, 11]. Crop monitoring and health assessment can include specific operations like identifying plant stress, nutrient deficiencies, and disease detection [32, 48]. Some research shows that the UAV in precision farming can be used for individual crop detection [18]. For some monitoring applications, specific sensors should be used, like LiDAR (Light Detection and Ranging) [44].

In addition, UAVs can be used in a way similar to traditional agricultural aviation methods. Field spraying carried out using unmanned aerial vehicles was adopted in the 1990s. At that time, the Yamaha R-MAX unmanned aerial vehicle was designed in Japan and is one of the most popular devices of this type [7]. Legal regulations in the European Union limit the use of drones for spraying, but performing agrotechnical treatments from the air has advantages in the form of access to places that may not be accessible to ground equipment and no need to use technological paths, which allows for operation, among others, in the middle of a disease outbreak without destroying healthy plants [11].

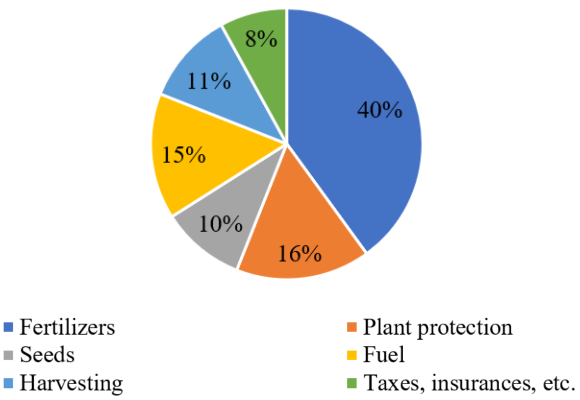

Fig. 4. Share of individual costs of rapeseed cultivation [50]

In precision aviation, collecting data on the condition of crops is key. For this purpose, various cameras and sensors are used, among which the most popular are [37, 48]:

1. RGB – Red, Green and Blue
2. VNIR – Very Near InfraRed
3. NIR – Near Infra-Red.

Data collected by the cameras mentioned above are then processed using appropriate algorithms, such as VARI (Visible Atmospherically Resistant Index) or NDVI (Normalized Difference Vegetation Index), which are most often implemented in computers located on board the UAV. Based on the results obtained, decisions are made on further agricultural treatments.

The RGB (Red, Green, Blue) camera is equipped with a matrix that receives red, green and blue light. It is, therefore, a camera of a similar design to modern devices used in smartphones or sports cameras, for example. These are high-quality cameras used mainly for visual observation of fields, for example, in search of wild animals that may cause damage. They also allow for an illustrative assessment of damage caused by droughts, hailstorms or floods [37].

Until recently, it did not provide data used in research algorithms. However, the VARI algorithm has been developed and is currently being used to provide an initial assessment of the health status of plants by appropriately manipulating individual receiving channels absorbing a given spectrum of light. This method is not as accurate as NDVI and is not intended to replace it; it allows only the detection of existing plant problems, not preventive action. However, it is cheaper and allows for use in virtually any commercial UAV with a standard camera. In addition, it does not require an on-board computer because the algorithm can be executed on a separate personal computer using the appropriate software installed [37].

The simplified formula for obtaining the results [37]:

$$\mathrm{VARI} = \frac{\mathrm{Green-Red}}{\mathrm{Green+Red-Blue}} \tag{1}$$

where the colors indicate the spectra of those colors.

A VNIR (Very Near Infra-Red) image recording device records not only the visible part, like an RGB camera, but also the near infrared spectrum; it therefore operates in the electromagnetic wavelength range from 400 to 1500 nanometers. They are most often modifications of RGB cameras, consisting of equipping them with appropriate near infrared filters. This camera allows for capturing the reflection of sunlight from a plant, visible in the near infrared. The UAV, making a free flight, collects this data and then it is processed using the NDVI algorithm.

The NDVI algorithm is a more advanced algorithm than VARI. The principle of the algorithm is that plants react to unfavorable conditions (disease, soil nutrient depletion or water deficiency) in the near infrared much earlier and more intensively than in the visible range. This algorithm draws data from a VNIR camera and uses both the visible and infrared light spectrum (Fig. 5). This allows for earlier detection of undesirable changes in vegetation development and more effective treatment of a given ailment through more precise selection of means, e.g. fertilizer or precise location of occurrence in a given area.

The simplified mathematical formula of the NDVI algorithm is as follows:

$$\mathrm{NDVI} = \frac{\mathrm{NIR-Red}}{\mathrm{NIR+Red}} \tag{2}$$

where: NIR – near infrared data, Red – data from the channel receiving red light.

Cameras operating on the NIR (Near Infra-Red) principle are multispectral and hyperspectral cameras. Devices with multispectral arrays can record up to seven spectral bands at once, compared to one band of VNIR cameras. This translates not only into greater accuracy but also a shorter time spent by the UAV in the air (fewer passes are required). Algorithms used on NIR data provide results with greater accuracy than the previously mentioned solutions; unfortunately, their field of view is narrower, and multispectral solutions are not susceptible to scalability [37].

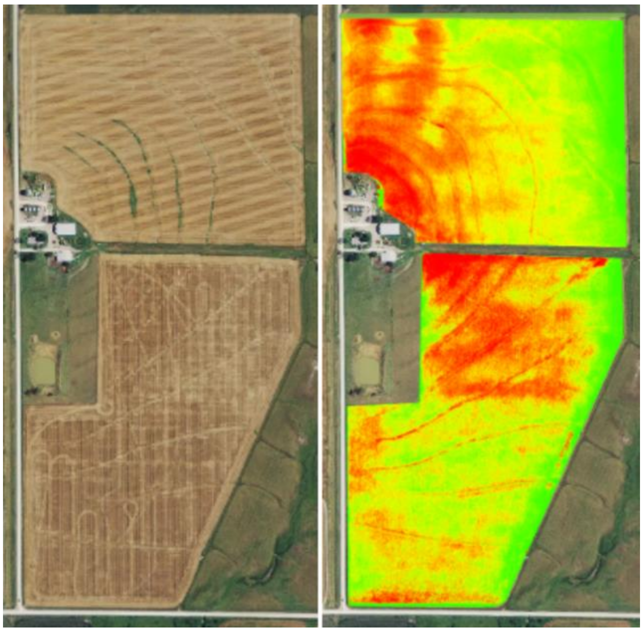

Fig. 5. RGB (left) and NDVI (right) maps comparison [37]

Hyperspectral arrays can not only operate on many visible light bands simultaneously, they are also the best quality devices for performing tasks for the NDVI algorithm. Their parameters allow for the detection of subtle diseases and pests and allow for the examination of the number of undesirable uncultivated plants in the fields (Fig. 6). This solution is also scalable to larger systems. Currently, NDVI-derived algorithms with greater capabilities for detecting individual ailments have also been developed for these cameras [28, 37].

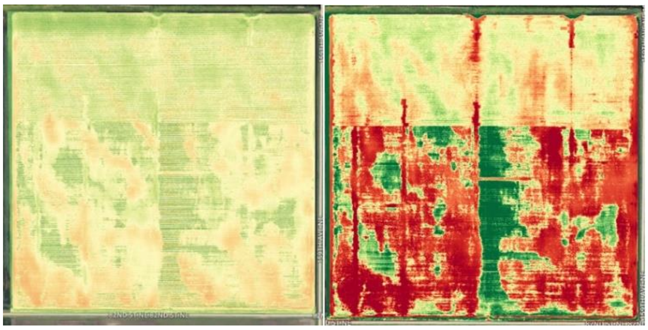

Fig. 6. Comparison of the output map from the VARI algorithm (left) and NDVI (right) [28]

Based on previously developed maps, it is possible to spray a given ailment or provide nutrients desired by plants in a given area. For this purpose, various types of drop tanks are installed with different volumes of collected material. They are usually made of plastic materials (e.g. ABS), less often of composites and can hold from 1 kg to 40 kg of agent. These tanks are most often equipped with several or a dozen nozzles distributing given agents over the area in the most even way possible. It is also possible to use fertilizers or loose agents from an appropriately small granulation. They are spread using a small round centrifugal spreader. Properly adapted flying devices can act as seed sowing. Of course, the UAV only scatters seeds, so the plant must be adapted to this method of propagation [16].

Unfortunately, drones used on the civilian market are not able to fertilize the entire crop area due to design limitations and legal requirements, but due to their ability to hover and fly at low speeds, they work very well in "point" operations – in a limited area. However, this problem can be solved by shuttle movement from the refuelling and energy replenishment point to the next unsprayed areas. With this method, one unit with the appropriate equipment and an automated station can handle up to 21 hectares in 1 hour. This technique can be improved and its performance increased by using several drones, communicating not only with the ground station, but also with each other in order to maintain safety and avoid unnecessary repetitions of operations [14, 20].

3. Aircrafts used in agricultural aviation

Due to the specific nature of this type of operation, agricultural aircraft must meet a number of design requirements. In addition to a large chemical payload, they should be characterized by good maneuverability when avoiding terrain obstacles. In addition, a strong fuselage and landing gear structure is necessary to enable operation from unpaved airports and a wing with mechanization facilitating short take-offs and landings. The pilot's cabin and engine must be protected from dust and chemicals. [2].

In the history of agricultural aviation, two generations of aircraft can be distinguished. [2]:

- Generation I – aircrafts temporarily adapted to agricultural aviation tasks. Widespread, especially in the early days of agricultural aviation, including training, multi-role and military aircraft withdrawn from service, including the British De Havilland DG-4 and the Soviet Po-2. Between the first and second generations, multi-role aircraft and helicopters with agricultural variants also appeared, including the An-2.
- Generation II – aircrafts designed to perform agricultural aviation tasks. Characteristic features of these structures include, among others, a reinforced cabin with increased forward visibility and a chemical tank placed between the cabin and the engine, increasing the pilot's safety in the event of a plane crash. Examples of second-generation agricultural aviation structures include the Piper PA-25 and the Rockwell S-2 Thrush Commander.

The first generation of agricultural aircraft includes the CSS-13 (Fig. 7), Which is a single-engine biplane with a wooden structure. It was produced in post-war Poland in the years 1948-1955 (initially in Mielec, later in Warsaw) on the license of the Soviet Po-2 aircraft [42]. The CSS-13 was a multi-role aircraft that was used as a training, sports, liaison, sanitary or agricultural unit. Agricultural aircraft in place of the rear cabin had a tank for chemical preparations holding 235–250 kg of the substance, and their hourly efficiency ranged from 16 to 36 ha. [36, 45].

Fig. 7. CSS-13 aircraft in The National Museum of Agriculture and Food Industry in Szreniawa [41]

The most popular agricultural aircraft was the An-2, which was developed in the Soviet Union (Fig. 8). At the same time, it is the largest single-engine biplane aircraft in the world. The An-2 was used in the military, transport and passenger aviation, but about 70% of all units were produced in the agricultural version An-2R [45]. The An-2 was the most widely produced aircraft in peacetime. 5200 units were produced in the USSR, 12,500 in Poland, and several thousand in China [45]. It was exported to all European and Asian socialist countries and to third-world countries.

Fig. 8. An-2R aircraft in The National Museum of Agriculture and Food Industry in Szreniawa [39]

For some agricultural work, especially in mountainous environments, helicopters have proven to be very effective. The Soviet multi-purpose helicopter Mi-2 (Fig. 9) was popular in agricultural work. It has an all-metal construction in a classic configuration (with a tail rotor) and is powered by two GTD-350 engines with a take-off power of 400 HP each. The agricultural version Mi-2R was used for dusting and spraying fields with loose or liquid chemicals. It had two laminated side tanks with a capacity of 600 dm^3 on the sides of the fuselage and pumps or fans (depending on the application) [12, 45]. Helicopters are also used in an unmanned form. In 1990, Yamaha introduced a small helicopter Yamaha R-50 with a payload of 20 kg, powered by a two-stroke engine with a displacement of 98 cm^3 (Fig. 10) [46]. This model was later replaced by the R-MAX model, the technical data of which are listed in Table 1.

In precision agriculture, where sometimes more time is needed for diagnostics and plant care, UAVs in the form of helicopters or multi-rotors are particularly useful, which allow for low-speed flight or hovering over a given area. In addition, such UAV configurations allow for placing various sensors and equipment on board, e.g. for sampling in hard-to-reach places, while relieving the farmer of certain duties, which translates into further savings, including time savings. One of the most popular drones for agricultural use is DJI Agras products. Currently, the largest and most advanced model is the DJI Agras T50, whose efficiency reaches up to 21 ha/h at a dose of 15 dm^3/ha [17].

Fig. 9. Mi-2R helicopter in The National Museum of Agriculture and Food Industry in Szreniawa [39]

Fig. 10. Yamaha R-50 unmanned helicopter [10]

It should be mentioned that manned aviation can also be used in precision farming. In that case the helicopters can be compared to multirotor UAV, because they can hoover. However, the use of manned flying machines will not be a good solution because the manned aircraft or helicopter still consumes much more energy. Maybe in the case of large fields, beneficial will be a "hybrid" use of the manned and unmanned systems – for example, the UAV can monitor the field, and the manned aircraft can spray the field because it can carry more chemicals than recent agriculture UAVs. That assumption will not be so precise because of different spraying devices, but it can save time for refilling the chemicals and changing batteries in the UAV.

Fig. 11. DJI Agras T50 drone in action [17]

A comparison of the performance characteristics of selected manned and unmanned agricultural aircraft is presented in Table 1. It can be observed that in the case of manned aircraft, the combustion engine was mainly used for propulsion, while in the case of unmanned units it is not so obvious. For this reason, Tables 1 and 2 provide fuel consumption per hour of operation for combustion units, while in the case of electric units, they provide electricity consumption.

Table 1. Basic technical data of selected agricultural aircraft [5, 6, 9, 11, 15, 17, 18, 38, 42, 43, 52]

	An-2R	PZL M-18 Dromader	Yamaha R-MAX	DJI Agras T50
Produced	1960–1991	1988–2012	From 1997	From 2022
Engine	9 cylinder radial engine, air cooled, 29,91 dm^3, type: ASz-62IR	9 cylinder radial engine, air cooled, 29,91 dm^3, type: ASz-62IR	2 cylinder flat engine, water cooled, 246 cm^3.	8 × electric motor
Engine power	736 kW (1000 KM)	736 kW (1000 KM)	15.4 kW (20.9 KM)	4 kW/motor
Curb weight	3360 kg	2470 kg	64 kg	52 kg
Payload	1200–1400 kg	2500 dm^3 or 1800 kg	30 kg	40 kg
Fuel (energy) cons. per 1 hr of work	175 dm^3	160 dm^3	n/a	9.45 kWh (calculated value)
Work efficiency	65 ha/hr	n/a	n/a	Up to 21 ha/hr

4. Estimation of the environmental impact of agricultural work using a manned and unmanned aerial vehicles

The An-2R aircraft and the DJI Agras T50 unmanned aerial vehicle were selected for the analyses. The former is powered by a piston engine, while the latter is powered by electric motors. For the An-2R the assumed work efficiency is described as "mean operational efficiency". For the UAV in the literature, the authors found the "maximum work efficiency". To make the analysis comparable, in the case of UAV, the authors assumed about half of the value given by the manufacturer. Because the emission factors for the piston engine collected in Table 3 are in g/kg fuel, further analyses assume the calculation of the mass of consumed fuel. In that case, a standard aviation gasoline density was assumed (Table 2).

Table 2. Assumptions for estimating toxic compound emissions

	An-2R	DJI Agras T50
Work efficiency	65 ha/hr	10 ha/hr
Fuel (energy) consumption per 1 hour of work	175 dm^3	9.45 kWh
Fuel (energy) consumption per 1 ha	2.7 dm^3 = 1.95 kg	0.945 kWh

To estimate the emission intensity of the analyzed agricultural aircraft, data made available in the report presenting emission factors for electricity produced in fuel combustion installations – for electric aircraft – were used. The values available in the tables present a mass of toxic compounds in relation to 1 kWh of produced electric energy [22]. In the case of an aircraft powered by a combustion unit, emission factors determined by the Federal Office of Civil Aviation were used, obtained from a piston aircraft engine powered by a carburettor – apart from the cylinder arrangement, this is a design similar to that used in the An-2R aircraft. The commonly used aviation emission factors are presented as a mass of toxic compounds to the mass of burned fuel (g/kg fuel). More accurate emission values for combustion engines could be obtained during exhaust emission testing, including the measurement of exhaust compound concentrations, exhaust gas flow and engine operating conditions [4, 33, 34]. The adopted factors are listed in Table 3.

Table 3. Emission factors adopted for piston aircraft engines and for electricity production in Poland [3, 22, 23, 30]

	Aviation piston engine [g/kg fuel]	Electric energy production [g/kWh]
CO_2	2967 (automotive gasoline)	788
CO	975	0.3
HC	19	n/a
NO_x	6	0.524
SO_2	0.21	0.502

Based on the calculations, estimated emission results were obtained for performing agricultural aviation treatments using an old generation of manned aircraft and a modern unmanned aircraft, which can be used to perform precision farming (Table 4). Based on the analyses, using an unmanned aircraft for agricultural aviation treatments instead of a traditional aircraft powered by a combustion engine allows for an estimated reduction in CO_2, CO and NO_x emissions by approx. 87%, 99.9% and 96%, respectively (Fig. 12). No estimates of changes in HC emissions were made because no such data were found for electricity generation. As for sulfur dioxide, for the adopted assumptions, the use of unmanned aircraft contributes to an increase in the emission of this compound by approx. 15%. This may be due to the higher sulfur content in coal used for electricity generation.

Table 4. Results of estimating the emission of harmful compounds during agricultural aviation work using an aeroplane and an unmanned aerial vehicle related to work over 1 ha of field

	Manned aircraft with piston engine [g/ha]	UAV with electric motors [g/ha]
CO_2	5786	744.7
CO	1901.25	0.28
HC	37.05	n/a
NO_x	11.7	0.495
SO_2	0.41	0.474

To receive more accurate emission values for both types of aircraft, real emission tests should be performed. For manned aircraft, to obtain the most relevant emission factors, the emission test should be preceded by the analysis of aircraft engine operation parameters in several agriculture flights [13]. Also, an analysis of energy consumption during real agriculture work should be performed using UAV emission estimation.

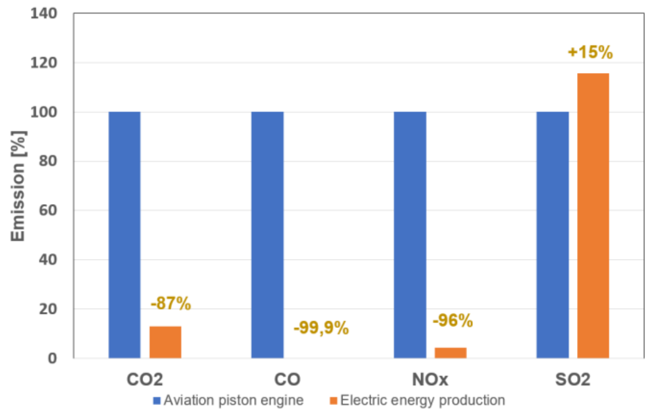

Fig. 12. Environmental impact of agricultural work with manned and unmanned aerial vehicle

It is worth emphasizing at this early stage that the vast majority of UAVs currently used in the European Union, not only in the agricultural sector, are powered by electric drives, which allows for the reduction of CO_2 emissions into the atmosphere.

Summary

Currently, agricultural aviation is commonly used in countries where agriculture is based on large-scale farms, including the USA [1]. In such conditions, aerial spraying speeds up field work and is economically profitable. In Poland, however, agricultural aviation has been replaced by modern ground-based agricultural equipment, and the smaller area of individual farms makes aerial spraying unprofitable. Additionally, in 2013, the Act on Plant Protection Products was passed, according to which spraying using agricultural aviation equipment can only be carried out when pest control is not possible using ground-based equipment or when it poses a lower risk to human or animal health or the environment [7].

A chance for further development of agro-aviation is precision farming, which is in line with the current trend of reducing the negative impact on the environment. In the case of precision farming, this is associated with reduced use of fertilizers and plant protection products. Moreover, as shown by the analyses conducted in this article, using unmanned aerial vehicles can also result in a significant reduction in the emission of pollutants into the atmosphere resulting from fuel combustion. As shown in the share of costs of individual agricultural treatments, in the cultivation of rapeseed, the costs of fertilization and spraying amount to approx. 56% of all costs, which allows us to conclude that modern cultivation methods will enable cost reduction while maintaining or improving the quality of crops.

The advantage of unmanned aerial vehicles is their modularity, thanks to which other sensors can be used when agricultural operations are not being performed, thanks to which the utilization rate of such a drone will be much higher, and therefore, its purchase can pay off in a shorter time. Unmanned aerial vehicles outside agriculture are used, for example, in searches carried out by the police, Central Bureau of Investigation of Police, or the Institute of National Remembrance.

For precision farming tasks, sometimes there is a need to fly slowly or even hoover over the treatment area. It narrows the possibility of choosing any UAV platform mostly to use the multirotor. One of the disadvantages of that configuration of UAV is short flight time on a single charge. This disadvantage requires interrupting work to replace the battery. This disadvantage is expected to be minimized in the near future [48]. In addition, the development of new propulsion systems, such as fuel cells, could enable increased flight endurance.

Another chance to increase the popularity of this method of conducting agricultural work is grassroots activation – for example, by aeroclubs, which could provide various types of services using unmanned aerial vehicles. Similarly, as was the case in the initial development stage of Poland's agricultural aviation [38].

Manned aircraft for agricultural use are still used in fighting forest fires, where, together with military helicopters, they constitute a basic tool in firefighting [2, 12]. In addition, aviation is useful in forestry, for example, for dropping rabies vaccines for forest animals such as foxes [2]. Unmanned aerial vehicles could support manned aircraft, for example, by monitoring forests to detect potential fires at their earliest stage.

Nomenclature

CMEA	Council for Mutual Economic Assistance
LiDAR	light detection and ranging
NDVI	normalized difference vegetation index
NIR	near infra-red
RGB	red, green, blue
UAV	unmanned aerial vehicles
VARI	visible atmospherically resistant index
VNIR	very near infra-red

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