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Effectiveness assessment of technical innovations in the implementation of the modern model of the agricultural sector of Ukraine

Volodymyr Mamchur
Doctor of Economic Sciences, Senior Researcher
National Scientific Center "Institute of Agrarian Economy"
03127, 10 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-1300-3633

Galyna Studinska*
Doctor of Economic Sciences, Senior Researcher
National Scientific Center "Institute of Agrarian Economy"
03127, 10 Heroiv Oborony Str., Kyiv, Ukraine
https://orcid.org/0000-0003-4713-4957

▸ **Abstract.** The agricultural sector of Ukraine requires fundamental changes to improve efficiency, rural development and sustainability, which is possible through the implementation of an innovative development model. The study aimed to assess the effectiveness of the introduction of one of the types of technical innovations – agricultural drones – in the agricultural production of Ukraine. The study uses the dialectical method of scientific cognition, analysis and synthesis, systematic generalisation, comparative analysis, rating method, and the mathematical method of calculation "solution optimisation" using Excel. The study analyses modern approaches to assessing the efficiency of individual processes, which helped to formulate its algorithm for calculating the efficiency of land cultivation using agricultural drones. At the first stage of the study, the technical advantages of agricultural drones were identified, which are manifested in increased labour productivity. The second stage of the study calculated the increase in the main crops (corn, wheat, sunflower, barley, soybeans, rapeseed, peas, buckwheat, and millet) that can be obtained as a result of the use of agricultural drones on a national scale. The third stage of the study yielded an indicator of the economic efficiency of introducing agricultural drones into agricultural production, as well as a forecast of the social and environmental effects. It is emphasised that state support for the Ukrainian production of agricultural drones in various forms (subsidies, preferential lending, leasing, etc.) will contribute to the development of innovative Ukrainian industry, which will positively affect the change in the sectoral structure of the national economy and significantly increase the country's gross domestic product. The following conclusions, suggestions and practical recommendations may be useful in developing relevant programmes and measures aimed at developing the agricultural sector of Ukraine

▸ **Keywords:** efficiency; agricultural sector; agriculture; innovation; agricultural drones; productivity; sectoral structure

▸ Introduction

The importance of fundamental changes in the development of the national economy as a whole, in particular in the agricultural sector, is determined by many scientists, practitioners and ordinary citizens who need a significant increase in the socio-economic conditions of well-being as a degree of satisfaction of human needs. The need to find and use innovative ways to overcome the extremely low standard of living in Ukraine is also clear. The war has further complicated the socio-economic situation in the country, which requires adequate actions to address its economic, environmental and social consequences, especially in the agricultural sector. O. Shubravska (2023), analysing the specialisation of Ukraine's agriculture and food exports, its pre-war trends and post-war prospects, notes that the negative impact of many factors on the post-war development of Ukrainian agriculture can be significantly reduced by intensifying *innovation processes*, which will also

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*Corresponding author

form the areas of specialisation of Ukrainian agricultural production and exports following the needs of long-term sustainability. V. Mamchur & G. Studinska (2023) prove that the fundamental reason for the economic lag of the Ukrainian economy with its significant natural (resource), geographical, and intellectual potential from modern developed technological countries is its *inefficient sectoral structure*, which requires government intervention, support from the legislature, and strategic and innovative changes in public administration. An analysis of changes in the sectoral structure of Ukraine's gross domestic product (GDP) shows that the trend towards an increase in the share of the primary sector, which includes agriculture, continues. A. Petrenko (2019) cites the results of a World Bank study that predicts that it will take Ukraine 40-50 years to catch up with Poland and 100 years to catch up with Germany in terms of living standards. The full-scale Russian invasion of Ukraine has exacerbated the impact of destructive processes in the development of the agricultural economy. The *raw materials export-oriented model of development of Ukraine's agricultural sector* has proved to be insufficiently sustainable and socially oriented. The current challenges may open new opportunities for agribusiness development, in particular, the agricultural economy should be restored to support small and medium-sized agribusinesses and promote the development of agricultural processing. K. Shatnenko (2023) emphasises that raw material specialisation stimulates the growth of economic inequality, constant problems with the country's balance of payments and dependence on external borrowing, and consolidates the oligarchic social structure, which is not interested in innovative development but has rent-seeking behaviour. The development of the processing industries prompts further research on changing the sectoral structure of Ukraine's economy. The changes should be significant, rapid, and permanent for a long time, which is possible only under conditions of a clear professional organisation of public administration and through the formation of an innovative model of agricultural development, which is presented as a set of technological, technical, organisational, institutional, legal, and marketing innovations. The introduction of each type of innovation requires an assessment of the effectiveness of their use and payback.

The transformation of the role of agriculture in Ukraine into a strategic one is deeply flawed. According to M. Kalinchyk *et al.* (2023), the reasons for the devastating misrepresentation of the role of agriculture in Ukraine are that "top managers of state institutions and final recipients of benefits from the exploitation of human, land, water and other natural resources have imposed on society the stereotype that the agricultural sector is the "engine of the Ukrainian economy", the "growth point", and that grain is "Ukrainian oil and gas". It naturally follows that being a raw material donor to industrialised countries is an honourable and "economic miracle", as Ukraine has historically had inexhaustible natural, human and other comparative and competitive advantages.

Global experience demonstrates an opposite practice that can provide a country with the desired economic breakthrough. Experts of the International Monetary Fund R. Chérif & F. Hasanov (2019) advise poor countries with a raw material structure to implement an active technology policy similar to that of the Asian tigers. They emphasise that standard recipes – improving the business climate, improving institutions, developing infrastructure, investing in education, and maintaining macroeconomic stability – are not enough to move to a dynamic and sustainable growth trajectory. They suggest three key success factors: 1) support for producers in *technology-based industries*; 2) export orientation; and 3) a commitment to fierce competition with strict accountability. These factors will certainly have an impact on changing the sectoral structure of the Ukrainian economy. A striking example of the use of these success factors is the economic achievements of South Korea, which has chosen an innovative path of development through the creation and promotion of technology brands.

The introduction of each type of innovation requires an assessment of the effectiveness of their use and payback, which determined the purpose of the study – to assess the effectiveness of the introduction of one of the types of technical innovations – agricultural drones – into agricultural production in Ukraine. According to the goal, the following tasks are set: 1) to collect and analyse information on the types of agricultural drones on the Ukrainian market; 2) to study their technical characteristics, advantages, disadvantages and price; 3) to substantiate the production potential of agricultural drones and assess the efficiency of agricultural drones in Ukraine.

▸ Literature review

Many scientists addressed the experience of innovation, in particular, O. Garazha *et al.* (2023), using comparative analysis, generalisation, synthesis and analysis methods for this process in Eastern Europe (to which Ukraine belongs), identify the development of innovations through the introduction of modern agricultural production technologies and the development of organic farming as promising.

Z. Yanchenko (2013) addressed the criterion of efficiency of innovation activity in agricultural production through "maximisation of profit per unit of agricultural land at minimum costs and optimal use of available capital and minimum environmental impact". The researcher emphasises that the assessment of the effectiveness of innovation in the agricultural sector should reflect the degree of rational use of land and other means of production, as well as the return on investment in agricultural production, which fully meets the requirements of the current national sustainability policy and affects our choice of method for assessing the effectiveness of agricultural drones in Ukraine. To assess the level of efficiency, the author proposes an index method, which involves calculating a list of indices: productivity growth, energy intensity reduction, productivity growth, reduction of environmental costs, and total costs of innovation. In addition, the author calculates the economic efficiency of innovations in the agricultural sector through their impact on the use of land resources.

A. Bakhtiar *et al.* (2022) assessed the productivity of innovation systems in different countries in general by considering two indicators of efficiency and effectiveness.

A *descriptive-analytical approach to assessing efficiency and effectiveness indicators* in 126 countries, including Ukraine, the USA, Switzerland, China, Iran, Armenia, Egypt, Australia, Qatar, Russia, and others was employed by comparing a range of indicators of socio-economic development and competitiveness. As a result, the researchers obtained a matrix with two vectors and proposed a corresponding classification of these countries. Ukraine received similar coordinates in this matrix, along with Moldova, Armenia, and Iran, where innovation systems are effective but inefficient, which reminds us of the need for comprehensive innovation changes in the country.

The result of a 6-year study of innovation effectiveness in manufacturing companies in various industries by J. Björk *et al.* (2023) was nine recommendations for improving innovation measurement in real practice, grouped into three main topics: strategy, organisation, and measurement design. A *case study analysis* was used to conclude innovation assessment efficiency. For the overall assessment of the effectiveness of our model of innovative development of the agricultural sector of Ukraine, it is useful to recommend not to overload mathematical calculations with a large list of indicators. Therefore, this study assesses the effectiveness of introducing only one innovation in agricultural production.

Given that the introduction of agricultural drones in Ukraine is intended for most small and medium-sized farms, the findings of W.A. Srisathan *et al.* (2023), who studied open innovation processes in 615 small and medium-sized enterprises in Thailand using the *second-order factor analysis* (a statistical method used to study the relationships between a set of sub-dimensions or factors that make up a higher-order construct), including multigroup analysis of structural invariance, were important for us.

Y. Ulko (2019) addressed the problem of assessing innovative measures and implementation in organic agriculture, and their adaptive and flexible use of modern and advanced technological solutions. The author used a combination of scientific methods to analyse various aspects of this problem, in particular, *constructive and calculation methods* to calculate the indicators of economic efficiency of yield growth from the application of biological products. As a result of the calculations made, the author concludes that the economic efficiency of organic production depends on the type of crop and the conditions of their cultivation, which proves the author's vision of a differentiated assessment of the efficiency of implementation of each agricultural innovation.

The methodological approach of Ukrainian researchers to assessing the effectiveness of innovative technology park projects by M. Petryna *et al.* (2020), based on globally accepted performance indicators: *net present value, profitability index, internal rate of return and payback period*, was used to conclude on the possibility of accelerating the process of selecting innovative projects and their implementation and intensifying innovation activities in the country. As a result of the study, the researchers focused on the need for stable legislation in Ukraine, which affects the performance indicators of innovative projects.

Correlation analysis and econometric modelling are widely used methods for assessing certain objects and processes in the national economy in general and in agriculture in particular. L. Kucher *et al.* (2022) used the first method to identify and assess the closeness of the relationship between the factors influencing the formation of financial support for the implementation of innovative projects of agricultural enterprises; the second method was used to build a *mathematical model of the dependence of investment profit of agricultural enterprises on production costs*. Other Ukrainian scientists L. Skorokhod *et al.* (2022) applied *correlation analysis* to assess the environmental and economic costs of using organic land for engineering and to evaluate the feasibility of developing organic production.

J.F. Reyes-Rodríguez *et al.* (2023) employed a *sustainable value creation model* and identified strategies suitable for small and medium-sized enterprises in Colombia, thus highlighting their potential in a developing country to contribute strategically to sustainable development, given their unique characteristics through the implementation of a portfolio of innovations.

The *cost method of calculating the efficiency* of agricultural drones in agricultural land cultivation is the easiest to apply, which contributed to its use by Ch. Mamedova (2020) in calculating the efficiency of using the Atrice 200 agricultural drone for aerial chemical work in the agricultural holding Mriya LLC. Using this method, the author predicted the amount of profit from this agricultural holding. The considered methodological approaches and research on assessing the effectiveness of innovations in the agricultural sector should be used to develop a methodology for assessing the introduction of agricultural drones in Ukraine.

Materials and methods

The empirical research was conducted according to the standard algorithm: 1) organisation – formation of research goals and objectives, selection of the object and subject of research, development of research methodology, drafting of a study plan; 2) achievement of the goal, which was carried out in three stages. The research was conducted at the National Research Centre "Institute of Agrarian Economics" in 2023. The study collected and analysed information on 20 types of agricultural drones for Ukrainian and foreign production.

The first stage of the study covered the research of agricultural drones offered by official dealers and Ukrainian manufacturers, as well as companies providing services for agricultural land processing with agricultural drones. The information was collected using the Internet and by phone. The results of the survey are presented in Table 1.

Table 1. List of agricultural drones, their performance and price in Ukraine for 2024

No.	Agricultural drone name	Functionality and productivity	Manufacturer/ supplier	Price, thsnd. UAH
1	Reactive Drone Agric RDE616 (PROF) Fuel tank of 20 litres	a) Spraying of plant protection products – 2-3.5 ha per cycle, up to 10-12 ha/hour; b) Spraying with organo-mineral fertilisers – 1.5-2.0 ha per cycle, up to 6-8 ha/hour; c) Solid fertiliser application – 1.0-1.5 ha/cycle, up to 5-6 ha/hour; d) Application of trichograms – up to 60 ha/hour.	Ukrainian manufacturer of agricultural drones – LLC "Reactive Drones", Dnipro, has been operating since 2016	500
2	Reactive Drone Agric RDE-410 Fuel tank of 10 litres	1) Up to 8 hectares/hour (up to 2 hectares per flight) – on simple fields without elevation differences with 500-1000 m spans; 2) Up to 6 hectares/hour (up to 1.5 hectares per flight) – on complex fields with small elevation differences and spans of 500-1000 m; 3) Up to 4 ha/hour (up to 1 hectare per flight) – on complex fields with elevation differences of up to 20 m and spans of 500-1000 m.		325
3	Reactive Drone Agroc RDE618 (PROF) 480,000 Fuel tank of 30 litres	For spraying plant protection products, fertilisers, and microelements. Professional model up to 15 ha/ hour (5 hectares per flight) on simple fields without elevation differences with spans of 500-1,000 m.		580
4	"Flying tractor" Fuel tank of 5-30 litres	Field cultivation, aerial reconnaissance, patrolling, mapping. In one flight (15 minutes), it can process up to 4 hectares of field with a working solution consumption of 2 litres/ha.	Ukrainian manufacturer IT KIT (n.d.), Kyiv presented domestic production drone in 2019	200
5	UAS6-50 Fuel tank of 50 litres	UAS6-50 productivity is 20 hectares per hour. 600 hectares per shift. Maximum speed of 8 m/s Maximum flight time is 129 minutes and minimum operating altitude is 1 m. Operational range – 3 km.		$55,000
6	UAS6-50G Fuel tank of 15 litres	Capable of cultivating any crops, orchards, vineyards, or forests (due to vertically turbulent flow of more than 20 m/s).		
7	Kray Protection Unmanned Aerial System Fuel tank of 22.5; 15 litres	Multi-rotor quadcopter for fertiliser application Drone productivity – up to 27-48 ha per hour, 300-500 ha/day.	Kray Technologies, Kyiv 2018	200
8	DJI Agros T30 Fuel tank of 30 litres	Processes up to 16 ha in one hour. Capable of recognising crops in any weather, from any angle.	Made in China DJI – 2/3 of global market	640; 660.5; 748
9	DJI Agros T 10 Fuel tank of 10 litres	Productivity is 40 ha/day.		209.3; 313.9
10	XAG V40 Standat mini kit (no LNT) Fuel tank of 16 litres	For MSMEs and agricultural producers with a land bank of 100 hectares or more. Covers up to 120-150 hectares in one shift. Maximum efficiency: 40 kg/min.		328; 370
11	XAG V40 Double kit 2 fuel tanks, each of 40 litres	Productivity of 2 drones per shift is up to 250 ha. During the desiccation of rapeseed, sunflower and other crops, a fleet of two drones ensures uniform application.		780
12	XAG P40 drone sprayer Fuel tank of 20 litres	Spraying, broadcasting, filming and mapping. Tank for applying plant protection products – 20 litres. Field map stitching performance – 6.67 hectares per 10 minutes.		315
13	XAG P100 Fuel tank of 40 litres	Spraying, sowing. Processing speed: up to 25 ha/h or 250 ha/10h. Payload: up to 40 litres or up to 70 kg of fertiliser and granules.		455
14	XAG P 100 pro 2023 agricultural drone Fuel tank of 50 litres	Processing speed: up to 30 ha/h or 250 ha/10h. Payload: up to 50 litres or up to 80 kg of fertiliser and granules.		1,500
15	XAG P100 Fuel tank of 40 and 60 litres	Capacity up to 5 tonnes per shift. The P100 is equipped with a 40-litre tank for working with pesticides and can process about 200 hectares in one shift.		330

Source: compiled by the authors based on DroneUA (n.d); ACASOM (n.d); Kray Technologies (n.d.); Reactive Drone (n.d.)

Stage two of the study involved collecting information on the conditions of use of agricultural drones, technical advantages and disadvantages of individual brands, prices of technical equipment or their lease, the cost of training to operate an agricultural drone and the cost of its maintenance, as well as the performance of agricultural drones, which provided grounds for a *comparative analysis* and *rating method* to identify the leaders among manufacturers, distributors and service providers of agricultural drones in the Ukrainian market. The information sources at this stage were the official websites of global manufacturers of agricultural drones (their official distributors, as well as feedback from consumers of services for the processing of land plots using agricultural drones).

The third stage of the research was devoted to the direct application of the mathematical method of evaluation "solution optimisation" using Excel to calculate the efficiency of using agricultural drones in agricultural land cultivation. The parameters used in the calculation were the production capacity of agricultural drones, including their speed and processing area, the amount of nutrient solutions consumed, and the structure of the land. The calculations were aimed to determine the optimal number of agricultural drones for processing agricultural land, considering its size, and to determine the number of agricultural drones that should be purchased or leased. This data was further used to calculate the efficiency of using agricultural drones, based on the projected increase in yields from their use and the average cost of an agricultural drone. The efficiency of using agricultural drones in the cultivation of agricultural land was calculated using the following formula:

$$E_d = \frac{\sum_i^n (V_i * P_i)}{\sum (V_j * P_j)}, \quad (1)$$

where E_d – additional income from the use of agricultural drones, billion UAH; V_i – increase in the volume of the harvest of the crop, thousand tonnes; P_i – average market price of the crop, UAH/tonne; V_j –the number of drones of the j-th type to be purchased by group 2 farmers, units; V_j – the average price of agricultural drones of the *j*-th type to be purchased, million UAH.

▸ Results and Discussion

L. Filipishyna *et al.* (2018), S. Ramazanov & M. Petrova (2020) emphasise that many enterprises are seeking ways to improve efficiency and maintain competitive advantages in the agribusiness sector, as in the context of the innovation economy and EU policy in the agricultural sector, green transformation, innovation can contribute to improving the efficiency of economic activity. The research methodology of the first group of Lithuanian scientists is based on a *combination of theories of economic system management in the context of globalisation, convergence and transnationalisation of the market economy*. The second group of researchers proposes modelling based on an *integrated object-subject approach, a conceptual model, and a generalised model of synergistic dynamics with uncertainties considered.*

A. Poltavets & M. Bahin (2022) addresses the issue of increasing the efficiency of land use as a factor in the growth of agricultural production, noting that "the efficiency of agricultural land use is the main factor that significantly affects the socio-economic situation both in individual regions and in the country as a whole", and therefore is the main mission of an agricultural entity. In this regard, the use of agricultural drones is a crucial element in preserving the quality of the land while increasing the productivity of farmers, yields (by reducing losses) and the efficiency of agricultural production in general.

Soil quality has a major impact on crop yields and requires a scientific approach to preserving, maintaining and improving this quality. G. Tigabu Asfaw (2023) investigated the need for soil and water conservation in different slope classes in Ethiopia and concluded that soil and water conservation improve soil erosion control results on steep slopes and has a significant impact on some physical and chemical soil parameters. The use of agricultural drones allows farmers to preserve soil quality by avoiding soil compaction and optimising the spraying of nutrients.

As a result of a comparative analysis of the efficiency of Ukrainian agriculture with European countries, V. Dmytriieva (2021) concluded that there is a positive trend in the development of agriculture in Ukraine, however, the current way of farming is insufficient and inefficient to become a prosperous country. Among European countries, Ukraine has the largest area of soil for sowing various crops, grains, vegetables, and fruits, but receives the lowest profit from land use. Agricultural production requires fundamental changes that can be achieved using agricultural drones, which are capable of significantly increasing farmers' productivity, crop yields, crop quality, and the overall economic and environmental efficiency of agricultural production.

Researchers, studying the state and trends in the development of innovation-oriented agriculture and food enterprises in the context of updating the management of business infrastructure and the business ecosystem, conclude that the use of more productive machinery reduces the security risks of agri-food enterprises due to higher labour productivity, respectively, wages, qualifications and motivation of employees. The efficiency of agricultural production is analysed through the dynamics of the indicator of agricultural land per employee. It is worth noting that this indicator characterises labour intensity rather than efficiency. An indicator of agricultural production efficiency is the yield, the volume of output per worker, or the volume of food exports per 1 ha of arable land. In particular, a study by M. Kalinchyk *et al.* (2023) shows that these are the indicators used in EU countries to assess the efficiency of agricultural production.

The analysis of the mentioned studies proves the relevance of performance evaluation and the dependence of its methodology on many criteria. Evaluation of the effectiveness of each project provides important information on the adoption of a certain strategy for the implementation of the object, the research process, or the selection of contractors for the implementation of this project, or on understanding the feasibility of the project in general, i.e. the results of the evaluation of effectiveness are a guarantee of certain project results or a warning of possible risks of its implementation. The choice of evaluation method primarily depends on the field of research, which determines a certain specificity of the choice of criteria

and indicators. Equally important is the information base of statistical data, its structure and scope, as the degree of accuracy of the results is directly proportional to the depth of the evaluation. These conditions influenced the choice of a method for assessing the effectiveness of the introduction of agricultural drones in Ukraine. It should be noted that this was the first time that such a task was carried out, which does not allow comparing the results with similar ones, but instead forms a source for comparative analysis in the future. The accuracy of calculations of the effectiveness of the use of technical innovations, in particular agricultural drones, will depend on the horizon of taking into account the factors and components of the revenue and cost parts formed in the process of applying this innovation to the country's agricultural production as a whole.

The analysis of the information collected at the first stage of the study (Table 1) demonstrated that most of the demand for agricultural drones by Ukrainian farmers is satisfied by foreign companies through official distributors, even though Ukrainian-made agricultural drones successfully compete with foreign analogues both in terms of technical characteristics and price. Ukrainian companies that manufacture agricultural drones find consumers all over the world, which proves their competitive ability. The problem of the prevalence of foreign-made agricultural drones in the Ukrainian market is related to the weak investment base in our country, as well as the non-competitive marketing policy of Ukrainian manufacturers to promote their products.

The extent to which agricultural drones are used in farming on a national scale depends on a deep understanding of the effectiveness of their use by farmers and financial support for their use by the state. Information on the productivity of agricultural drones, considering their working potential, and the structure of land by size, gave rise to the division of agricultural producers into two groups. The first group includes business entities that cultivate land plots from 5 to 50 hectares, for which it is advisable to use the services of agricultural drones, and the second group includes business entities that cultivate land plots of 50 hectares and more, which are interested in owning agricultural drones, as shown in Table 2.

Table 2. Calculating the number of agricultural drones in Ukraine by 2030

	Entities with agricultural land		Estimation of the number of agricultural drones in Ukraine		
	units	Land area, ha	Average area of 1 p/a, ha	Normative need for agricultural drones, units	Total number of agricultural drones, units
Drone rental					
Up to 5 ha	1,766	5,818	3	1	1,766
5-10 ha	1,827	14,318	8	1	1,827
10-20 ha	3,036	47,206	16	1	3,036
20-50 ha	9,460	353,432	37	1	9,460
Total:	x				**16,089**
Drone acquisition					
50-100 ha	5,167	373,475	72	1	5,167
100-500 ha	9,371	2,290,292	244	1	9,371
500-1000 ha	3,228	231,4079	717	1	3,228
1000-5000 ha	4,845	10,150,358	2,095	2	9,690
More than 5000 ha	601	5,273,845	8,775	3	1,803
Total:	x				**29,259**
In Ukraine in total:	39,301	2,0822,823	x	x	x
Total number, of units					**45,348**
Costs, million UAH	x				20,481

Source: compiled by the authors

The estimates in Table 2 show that the total number of agricultural drones required for farming in Ukraine is 45,348 units, of which 16,089 units are required through farming services and 29,259 through the purchase of agricultural drones. The total cost of the drones in the latter group was calculated based on the average price of an agricultural drone – 700 thousand UAH.

According to the Ukrainian Club of Agrarian Business Association of the Union of Ukrainian Entrepreneurs and DroneUA, the largest integrator, importer and distributor of the world's leading drone manufacturers (2023), 2.2 million hectares of land were cultivated by agricultural drones in 2021 and 2022; up to 350 thousand tonnes of crops were additionally harvested; fuel savings of up to 12.1 million litres were achieved (compared to conventional wheeled vehicles); as an environmental effect, carbon emissions were reduced by 30.8 thousand tonnes, and water savings amounted to about 440 thousand tonnes (Union of Ukrainian Entrepreneurs... , n.d.; DroneUA, n.d.). In addition, up to 1,000 jobs were preserved, which is crucial in a time of war. According to DroneUA (DroneUA, n.d.), the elimination of soil compaction using agricultural drones alone reduces crop yields by at least 20%, and the absence of damage to crops by the wheels of ground sprayers adds 5 to 10% to the yield.

In addition to preventing soil compaction and crop damage, the increase in crop yields will be influenced by the accuracy of fertiliser application, timely desiccation, increased spray efficiency due to the optimal droplet size of the solution, etc., but there is no data on the result of such an impact yet, which is why further calculations of

the efficiency of agricultural drones should be based on the minimum value mentioned above – 30% (20% + 10%).

The expected increase in harvest volume for the main crops grown in Ukraine in 2023 is shown in Figure 1.

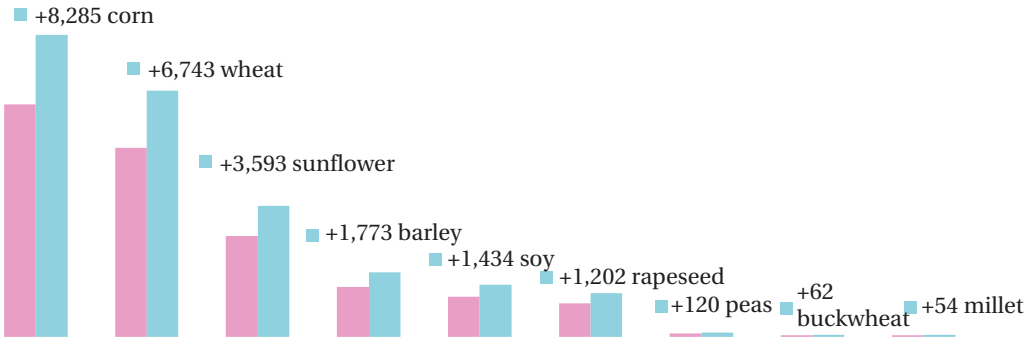

Figure 1. The annual increase in the yield of major crops due to the use of agricultural drones, thousand tonnes
Source: calculated by the authors

Based on these data, the estimated annual additional income that can be generated using agricultural drones by all business entities in agricultural production is presented in Table 3. The calculations show that the total projected additional income for the main crops alone could amount to almost 133 billion UAH.

Table 3. Annual additional income from increased yields generated by using agricultural drones

	Volume, thousand tonnes	Growth, thousand tonnes	Average price, UAH/t	Additional income, UAH million
1	2	3 = 2 * 30%	4	5 = 3 * 4
Corn	27,615	8,284.5	5,200	43,079.40
Wheat	22,478	6,743.4	4,800	32,368.32
Sunflower	11,975	3,592.5	3,647	13,101.85
Barley	5,909	1,772.7	1,772	3,141.22
Soy	4,779	1,433.7	16,200	23,225.94
Rapeseed	4,005	1,201.5	13,500	16,220.25
Peas	400	119.9	7,938	951.37
Buckwheat	208	62.3	9,000	560.25
Millet	180	54.0	6,373	344.14
Additional income, UAH million		x	x	**132,993**

Source: calculated by the authors

The effectiveness of the use of agricultural drones in the cultivation of agricultural land is calculated using the conventional formula (1). The efficiency of using agricultural drones in the cultivation of agricultural land will be 649%, according to the calculations in Formula (1), which means that the payback period for investments in such an innovation is minimal. For a farmer, an investment of 700,000 UAH or more is substantial, therefore, government support for the introduction of agricultural drones will not be superfluous. The form of such support can be different – low lending rates, leasing, subsidies, etc. Moreover, state support for the Ukrainian production of agricultural drones will contribute to the development of an innovative industry, which will positively affect the change in the sectoral structure of the national economy and significantly increase the country's GDP.

The cost part of the calculation of the effectiveness of the introduction of agricultural drones in practice will be increased due to the high payment for the operators of agricultural drones, payment for their training, and maintenance of these innovative technical means. At the same time, the income can also be increased due to the above-mentioned savings in water, energy, and fertilisers, as well as from an additional increase in yields, which is not accounted for and mentioned above. The availability of such statistical data will refine efficiency calculations.

A significant socio-economic effect of the introduction of agricultural drones in agricultural production will be an increase in the number of young people who will have material reasons to stay in rural areas and develop them. Given that the additional effect reported by DroneUA was obtained from the use of agricultural drones on an area of 2.2 million hectares, and the total area of Ukrainian land is much larger, the additional annual environmental effect should include a reduction in carbon emissions of up to 350 thousand tonnes, water savings of up to 4,500 thousand tonnes, and a reduction in fuel consumption of up to 120 million litres, which is a significant contribution to the national sustainable development programme (DroneUA, n.d.). The results obtained demonstrate that there is a significant economic effect from the use of agricultural drones in Ukrainian agriculture. The environmental effect

of the use of agricultural drones is also noticeable, which makes their introduction on a national scale attractive. The calculations of the effectiveness of the use of agricultural drones on a national scale are a precedent for their comparison with similar ones in the future.

Conclusions

The challenges in Ukrainian agriculture have deep political roots, which are manifested in the inefficient sectoral structure of the national economy, where the share of the primary sector, which includes agriculture, is more than three times the global average, which significantly hinders the country's further development. The sectoral structure of the national economy is a basic determinant of the country's GDP, which is why there is not a single country in the list of developed countries that has chosen agriculture as the mainstay. Given the strategic role of Ukrainian agricultural production in shaping domestic food and national security, as well as its role in the global food market, the agricultural sector needs to undergo fundamental changes through the implementation of a system of innovations (technical, technological, organisational, institutional, marketing) that can significantly improve the efficiency of agricultural management, ensure a change in the sectoral structure of the national economy in favour of high-tech processing industries, and create a new economy. In particular, the use of agricultural drones in farmland cultivation can be one of the most powerful innovative solutions that will not only increase yields but also bring an additional annual GDP income of up to 133 billion UAH. The social and environmental effects that will result from the use of this innovative technology will be significant: a reduction in carbon emissions of about 350,000 tonnes, water savings of 4.5 million tonnes and fuel savings of 120 million litres, creation of new high-paying jobs, development of social infrastructure in rural areas, increased income levels and a significant improvement in the socio-economic conditions of rural residents. Further research will be focused on analysing and assessing the economic efficiency of agricultural drones in horticulture and vegetable growing, as well as conducting a comparative analysis of their use in comparison with the use of ground-based agricultural machinery, including ground-based agricultural drones.

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None.

Conflict of interest

The authors of this study declare no conflict of interest.

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Оцінка ефективності впровадження технічних інновацій в реалізації сучасної моделі аграрної сфери України

Володимир Мамчур
Доктор економічний наук, старший дослідник
Національний науковий центр «Інститут аграрної економіки»
03127, вул. Героїв Оборони, 10, м. Київ, Україна
https://orcid.org/0000-0003-1300-3633

Галина Студінська
Доктор економічний наук, старший дослідник
Національний науковий центр «Інститут аграрної економіки»
03127, вул. Героїв Оборони, 10, м. Київ, Україна
https://orcid.org/0000-0003-4713-4957

► **Анотація.** Аграрна сфера України потребує кардинальних змін для підвищення ефективності, розвитку сільських територій та стійкості, що можливо завдяки впровадженню моделі інноваційного розвитку. Метою статті було здійснення оцінки ефективності впровадження у аграрному виробництві України одного з видів технічних інновацій – аграрних дронів. У процесі дослідження використано діалектичний метод наукового пізнання, аналізу й синтезу, системного узагальнення, порівняльного аналізу, метод рейтингування, а також математичний метод розрахунку «оптимізація рішення» засобами Excel. В дослідженні розглянуто сучасні підходи до оцінки ефективності окремих процесів, що допомогло сформувати власний алгоритм розрахунку ефективності обробки земельних угідь засобами аграрних дронів. На першому етапі дослідження встановлено технічні переваги аграрних дронів, що мають прояв у підвищенні продуктивності праці. За другим етапом дослідження було розрахований приріст по основним сільськогосподарським культурам (кукурудза, пшениця, соняшник, ячмінь, соя, ріпак, горох, гречка, просо), що може бути отриманий, як результат застосування аграрних дронів в масштабах України. Результатом третього етапу дослідження став показник економічної ефективності впровадження в аграрне виробництво аграрних дронів, а також прогноз розрахунків соціального та екологічного ефектів. Підкреслено, що державна підтримка українського виробництва аграрних дронів у різних формах (субсидії, пільгове кредитування, лізинг тощо) сприятиме розвитку інноваційної української промисловості, що позитивно вплине на зміну секторальної структури національної економіки та суттєво збільшить валовий внутрішній продукт країни. Висновки, пропозиції та практичні рекомендації можуть бути корисними у розробці відповідних програм та заходів, спрямованих на розвиток аграрної сфери України

► **Ключові слова:** ефективність; аграрна сфера; сільське господарство; інновації; аграрні дрони; продуктивність; секторальна структура