

Financing innovations in the agricultural industry as a component of the digital development of Ukraine's economy

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Abstract. Innovative development of the economy is a condition for stable growth, which holds particular importance for the agricultural sector, elevating the management of biological assets to a significantly higher level. This study aims to determine the potential for innovative development in the agricultural sector of Ukraine and investigate the peculiarities of its financing. General scientific methods and hermeneutic methods were applied, along with statistical and correlation methods, to identify the connection between influencing factors. Tabular and graphical methods were used to present the results, and generalization was employed for drawing conclusions. The study assessed Ukraine's positions in the Global Innovation Index (2014-2022), which is relatively low, decreasing from 63 to 57 over the period. However, it shows potential in components like human capital, the business environment, and scientific research. The dependency of the growth of agricultural GDP on various factors was identified through correlation and variance analysis, particularly through the advancement of innovations. The structure of GDP dynamics reveals a decline in the agricultural sector by 28% in the wartime of 2022 compared to 2021, while the information and telecommunication sector only decreased by

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7%. If the pre-war level of government spending on financing agricultural innovations was 80% of the total, covering only the reproduction of conditions for the formation of scientific products, even raising it to 90% during the wartime does not meet real needs. Scientific and educational expenditures of the Ministry of Agricultural Policy and Food from 2018 to 2023 decreased by 22% in terms of funds, while their share increased from 4.45% in 2018 to 8.57% in 2023 due to the overall decrease in funding by 67%. Based on the assessment of the state of financing innovations in the agricultural sector to enhance them, a systematic approach to choosing financing sources was proposed. An optimal financing scheme for agricultural innovations was built based on consolidated sources under the conditions of forming a financial cluster. The practical significance of the research lies in the possibility of using its results in developing a strategy for post-war recovery of the agricultural sector. This involves evaluating the effectiveness of models for financial support of innovative development

Keywords: funding sources; scientific support; budget; digitization; financial cluster

Introduction

The digital direction of economic development worldwide shapes the knowledge economy. The tools of this economy are widely applied in the agricultural sector, where the diverse nature of production, spatial stability, and cyclical processes logically structure into a comprehensive system through the application of digitalization tools. This contributes to a rapid increase in the competitiveness of enterprises utilizing digitalization tools.

In wartime conditions, according to researchers and the relevant ministry, the value-added chains of the agricultural sector have significantly distorted due to disruptions in internal logistics and export-import operations concerning geography and production structure, dependence on “grain contracts” under the auspices of the UN, energy and fuel crises, market declines in material resources such as seeds, plant protection agents, fertilizers, animal feed, loss of territories for operations due to active combat, disruptions in production infrastructure, deterioration of enterprise production capacities, loss of human capital due to forced migration and mobilization, cessation of direct government support and compensation for destroyed production assets, and a decline in the purchasing power of the population. As a result, financing for the agricultural sector is prioritized to ensure at least zero profitability, leading to minimal expenditures on innovations in these conditions.

However, post-war reconstruction will demand unconventional steps to restore economic and agricultural potential, and one such step is innovative development. For the agricultural sector, this involves the creation and implementation of digital and nanotechnologies, the utilization of achievements in bioeconomics, organic farming, green economics, and the application of renewable energy resources. In turn, smart economic technologies require new approaches to financing, expanding their directions, sources, and efficiency. This is essential because the digitization of the agricultural sector is intensifying globally, becoming significant not only for developed nations but also for third-world countries. Therefore, domestic agriculture in innovative development needs to align with the best global practices.

Analysing the vision of the future of digital agriculture formulated by the Food and Agriculture Organization

(FAO), the Organization for Economic Cooperation and Development (OECD), and the World Bank, one dominant narrative revolves around digital technologies as a solution to food security and hunger issues. The imperative of sustainable development supports the need for digitizing agriculture. The assessment of the European Union’s “From Farm to Fork” (F2F) strategy, launched in 2020, aiming for a comprehensive transition to sustainable development in the European agri-food sector, indicates that political will alone will not achieve its ambitious goals. Success largely depends on innovations, both scaling existing ones and developing entirely new ones.

Global scientific thought explores new digital technologies and services available to farmers for resource acquisition, digital financing, and access to management information. The key challenge lies in the unequal accessibility of digital technologies for different groups of farmers, and scholars suggest investing in state research and development works (R&D) to limit market concentration. Agricultural technology issues are linked to the possibility of changing financing, as digital technologies alter the configuration of the agricultural financial landscape. As digital technologies reshape decision-making in agricultural production, it is crucial to determine how these technologies can be used not only for private goods but also for public goods, particularly ecological purposes. Global challenges such as climate change, global warming, extreme weather catastrophes, and unexpected disruptions are growing concerns for the economy, prompting the study of new advanced possibilities of digital technologies.

High-level political documents dedicated to the future of global digital agriculture and sustainable food systems underscore the need for a careful assessment of the contribution digital agricultural innovations can make to addressing 21st-century challenges. The role assigned to digital technologies by international entities in influencing the future of food, financing, design, management, and implementation of digital agricultural innovations is a critical aspect. Regulating this process in Ukraine requires scientific support. Therefore, researching the financing of innovations in the agricultural sector as a component of Ukraine’s digital economic development is a relevant scientific task.

The goal of this study is to determine the potential for financing the innovative development of Ukraine's agricultural sector in the conditions of economic digitalization. The research task is to assess the current state of innovations in the agricultural sector, their funding sources, and the efficiency of financing models for post-war recovery based on potential assessment.

Literature Review

The essence of the digital economy, as defined by researchers, lies in "the use and dissemination of knowledge in all fields and sectors of the economy, as well as the creation of knowledge to develop intellectual potential, utilize high-intellectual human capital to enhance the competitiveness of the national economy, and create a new innovative base for its development" (Maslak *et al.*, 2020). It is also studied as the economy of spatial knowledge, new knowledge infrastructure through the role of technology-based business services in national innovation systems (den Hertog & Bilderbeek, 2001), and so on. Generally, it is recognized that the knowledge economy is based on the development of human capital, the use of information technologies, highly skilled personnel, the activation of innovative activities, and it predominantly specializes in providing services and using high-intellectual labour.

Additionally, it is noted (Birner *et al.*, 2021) that digital agriculture has extensive opportunities for accelerating transformation and is evolving through private firms, including well-known resource production firms, global software companies, and startups that are new to agriculture. The features of innovation process in the agricultural sector are revealed by researchers in terms of innovative marketing tools to enhance the competitiveness of agricultural enterprises (Holsheva, 2021). This includes two components of innovative marketing in the management of agricultural enterprises: innovation marketing (product innovation: biological innovations; technology innovation: technical and technological innovations; service innovation: social, economic, and organizational innovations) and innovation in marketing (innovations in product, price, communication, and distribution policies of agricultural enterprises).

From this, it can be observed that innovation financing also has a dual significance, both as the allocation of funds from sources for the creation or implementation of innovations and as innovative financing methods inherent in the digital economy: blockchain and cryptocurrencies, fintech, mobile financial applications, financial and accounting management, electronic money, robo-advisors, insurance technologies, crowdfunding, P2P lending, etc. Institutional determinants of innovation development (Honcharenko *et al.*, 2019) predict that the implementation of justified alternative scenarios of innovation development should be based on a corresponding concept aimed at optimizing resources. In this approach, in the projection to financing, the determination of the optimal combination of resources and results of innovative activity cannot be reduced solely to direct economic benefits.

The need for activating innovative activity to ensure food security, carrying out innovative industrialization (Osetskyy & Kulish, 2020), was discussed in the pre-war period of innovation, in the agricultural sector in the context of the development of European integration (Dorosh-Kizym *et al.*, 2017). With the consideration of industry losses from war and the needs for its recovery, innovation issues have become paramount. Researchers have also considered the problems of financing the innovative development of the agricultural sector in terms of expenses and sources of coverage (Radchenko, 2023; Roieva *et al.*, 2023), indicating the dynamics of the share of innovation-active enterprises and their expenditures on innovative activities. These indicators do not show a clear trend of growth, necessitating the stimulation of innovative activities of enterprises, especially at the state level. The insufficient involvement of the state in the digitization process in enterprises is also confirmed by the reduction of state funding for innovative activities of enterprises.

Researchers have described the functioning of typical financing models based on the amount of required financial resources, terms, their cost, and the possibility of attraction (Sus *et al.*, 2023). These researchers have analysed a cluster financing model that can be applied to the implementation of important and valuable innovative projects, allowing to combine and stimulate all participants in the innovation process to achieve the planned result with optimal financing, diversify risks, and objectively assess the borrower's activity, particularly in terms of the efficiency of using financial resources in the implementation of an innovative project. The researchers have also justified the need for the formation of program innovative development packages (Shpak & Fedorchuk, 2021) while adhering to the requirements of innovative resource-environmental safety of economic activities, purposeful and consistent transition to a sustainable development model, which means simultaneous solution of economic, social, and environmental problems of society, and so on.

Innovation and its dissemination are one of the priorities of the Ministry of Education and Science of Ukraine, specifically focusing on the development of the science sector and the activation of innovative activities to increase the prestige of Ukrainian science, ensure industrial competitiveness, and promote the development of high-tech production by tripling the knowledge intensity of GDP. This includes addressing global challenges through collaboration with leading countries and engaging with the scientific diaspora (MES, 2023). Additionally, innovation in the agricultural sector is under the purview of the Ministry of Agrarian Policy and Food of Ukraine, particularly through state funding for science and education in the agricultural field (MAPF, 2023).

According to researchers from the Ukrainian Institute of Scientific and Technical Information (Pisarenko *et al.*, 2023), the global agriculture sector, due to the evolutionary development of technologies, is currently in the 4.0 stage ("Agriculture 4.0"). It is oriented towards the use of

environmentally friendly natural resources such as solar and seawater, employing advanced innovative technologies in precision and smart agriculture. This includes genetic modification, nanobiotechnology, non-soil plant cultivation, vertical farming (based on hydro-, aqua-, and aeroponics), as well as complex technological systems like satellite navigation, robots, drones, 3D and 4D printing of food products, the Internet of Things, blockchain, and more. It is predicted that the next stage of evolution, "Agriculture 5.0," will be based on comprehensive automation of agri-food production using various forms of artificial intelligence.

Considering the overall state of innovation financing in the agricultural sector and the partially formed directions discussed by researchers, there is a need for an in-depth study of the state and prospects of innovation financing in the agricultural industry as a component of Ukraine's digital economic development.

Materials and Methods

The methodological basis of the conducted research is a systemic approach, which is applied to reflect the connections between the studied processes. To obtain new results in the research, interdisciplinary scientific methods were utilized, including the systematization of the regulatory framework for innovation development; comparative analysis – when examining funding sources; hermeneutic method – for research definitions of concepts such as agricultural innovations, financial clusters, statistical analysis – to identify the correlation between selected factors influencing the development of digitization of the economy on the level of the agricultural GDP; generalization – for formulating conclusions. The research employed graphical and tabular methods for visually presenting the research results. This includes depicting the dynamics of the global innovation index and GDP volumes, as well as highlighting the results of statistical correlation analysis of factors influencing the agricultural GDP. The research methodology takes into account the fact that the transition to a digital economy is carried out with a key role played by ICT, considering that the volumes significantly impact the efficiency of the economy's functioning and all its sectors. The dynamics of GDP volumes and the structure of specific economic sectors in Ukraine from 2014–2022 were analysed to determine the share of digital services and compare their growth rates with the agricultural sector.

The main indicators for evaluating innovation development were determined based on regulatory documents and analysis of scientific sources. Initial data for calculating the correlation of factors influencing the agricultural GDP were selected, considering general trends in the development of the digital economy and data available for analysis. Regression statistics and analysis of variance were performed using the "Data Analysis" package in Excel. Analysis of variance was used to test hypotheses about the relationship between a specific feature, namely the volume of agricultural GDP and the studied factors, to establish their degree of influence and interaction. Regression

analysis predicted methods for building a model of interaction between innovation expenses and the volume of agricultural GDP, methods for determining the parameters of the model, and checking its reliability.

Regarding state support for innovation in the agricultural sector, methodological approaches and generalizations were made based on the directions of funding for science, scientific and technical activities, and education. The scheme of the financial cluster mechanism for the needs of financing agricultural innovation development was constructed based on an algorithm, the basic steps of which were determined by the regulatory field and the practice of innovation activities and methods of its assessment.

The research is based on legislative documents, including Law of Ukraine No. 1667-IX "On Stimulating the Development of The Digital Economy in Ukraine" (2021, July), Order of the Cabinet of Ministers of Ukraine No. 526 (2019, July), Law of Ukraine No. 40-IV "On Innovation Activity" (2002, July), Law of Ukraine No. 3715-VI "On Priority Areas of Innovation Activity in Ukraine" (2011, September), Resolution of the Cabinet of Ministers of Ukraine No. 13 (2018, January), Resolution of the Cabinet of Ministers of Ukraine No. 1056 (2016, December), as well as calculations and forecasts of the Government of Ukraine and International Organizations regarding the state of the research object. Generalization and analysis of data using the provided methodological-informational toolkit allow revealing the features of financing innovations in the agricultural sector as a component of Ukraine's digital economic development.

Results and Discussion

According to the research conducted by the World Bank Group's Enabling the Business of Agriculture (EBA), which collects global data on regulations affecting farmers, indicators supporting agricultural business development provide comparisons of regulatory acts related to agricultural resources, plant health, access to financing and markets. They demonstrate variations among countries in the effectiveness of implementing regulatory acts. In 2019, the thematic score for EBA in Ukraine was 67.40 out of 100, with specific scores as follows: seed supply – 54.93; fertilizer registration – 43.33; water provision – 60.00; machinery registration – 80.65; livestock conditions – 65.00; plant protection – 100.00; certified food trade – 65.29; access to finance – 70.00 (Enabling the Business of Agriculture, 2019). In other words, the financial resources available to Ukrainian farmers, encompassing funds for current and investment activities, were relatively high, even by international standards, aligning with the overall state of the innovation economy.

Ukraine's position in the Global Innovation Index (GII, 2023) and its components, as shown in Figure 1, indicates minimal changes from 2014–2022. It held the 63rd position in the country rankings in 2013, reaching its highest level in 2018 at 43, but it decreased to 57 in 2022. The breakdown of the index components reveals that the business environment, human capital and research, creativity, knowledge,

and research results are stronger indicators. On the other hand, regulatory environment, market development, and

information and communication technologies are considered weaker aspects (Tkach & Dendebera, 2023).

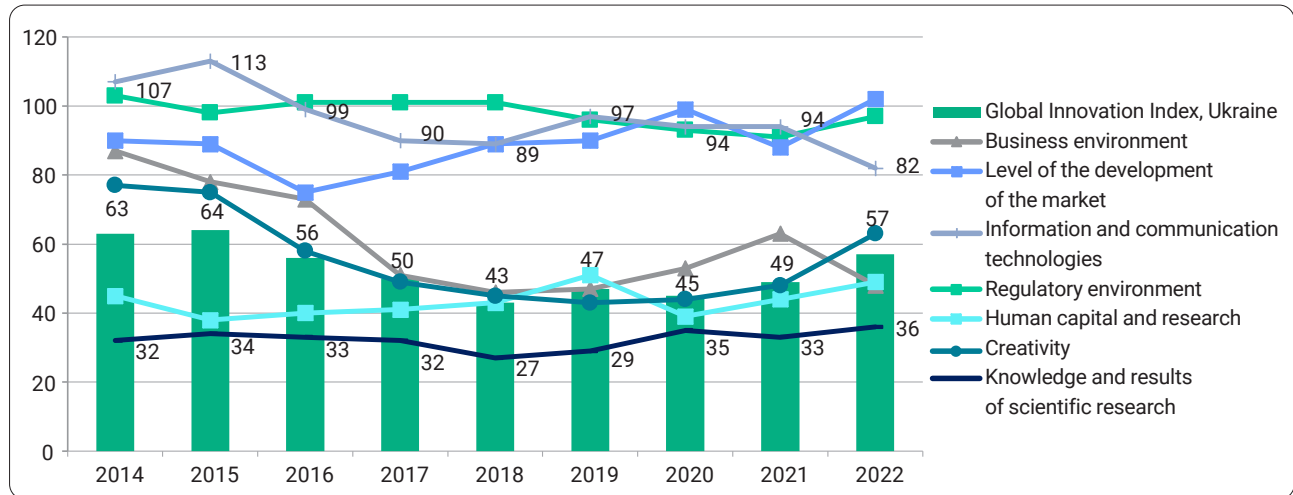


Figure 1. Dynamics of the Global Innovation Index and its components for Ukraine for 2014-2022

Source: developed by the authors according to the Global Innovation Index (2023)

According to the data from the Institute of Intellectual Property (2023), among the key indicators of innovation development analysed by researchers and applicable to the agricultural sector, the following are used: human resources or potential characterized by the number of people with higher education and those engaged in lifelong learning; digitization through broadband internet coverage; the number of people with basic digital skills; finances in terms of spending on research and development in the public sector, venture fund expenditures, state support for research and development carried out by commercial structures; investments from the commercial sector, including spending on non-research-related innovations;

the use of information and communication technologies (ICT); sales of innovative products; environmental sustainability, including resource productivity, atmospheric emissions, and ecological technologies, among others.

The dynamics of GDP volumes and the share of specific economic sectors in Ukraine from 2014 to 2022, as shown in Figure 2, indicate that the decline in agricultural GDP occurred more rapidly than in the ICT sector. If the share of the ICT sector in the agricultural GDP was 33% in 2014, it reached 56% by 2022. The decline in the volume of the agricultural sector in the war-torn 2022 compared to 2021 was 28%, while the ICT sectors experienced only a 7% decline.

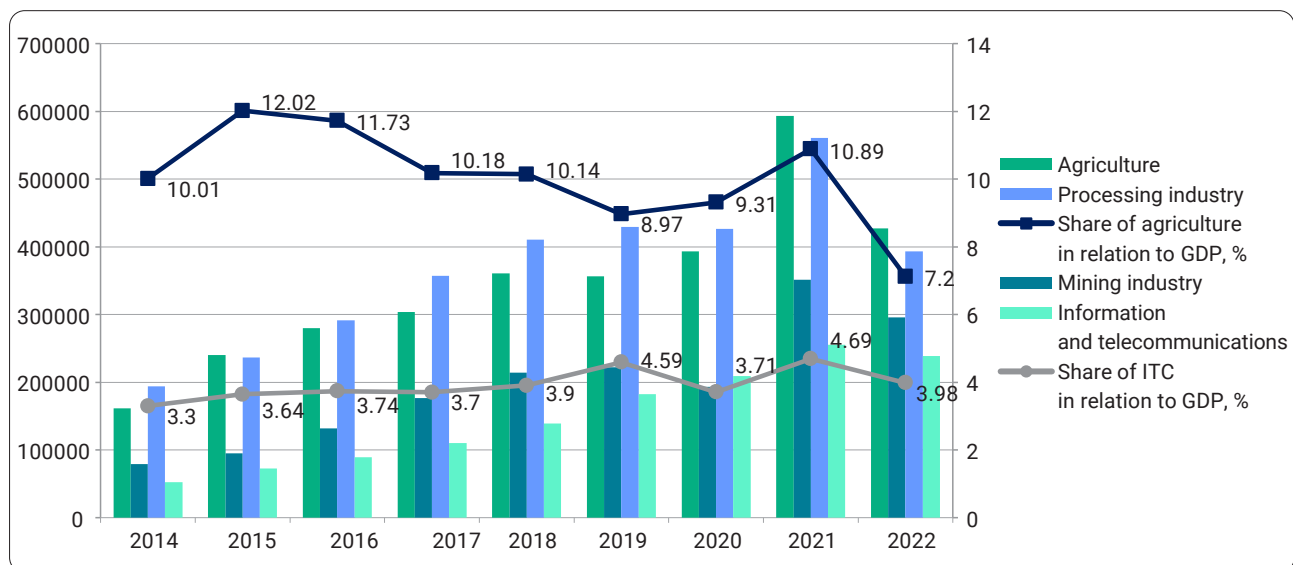


Figure 2. Dynamics of GDP volumes and the share of individual branches of the economy of Ukraine for 2014-2022, UAH million, %

Source: developed by the authors based on the data from the State Statistics Service of Ukraine (2023)

Considering the general trends in the development of the digital economy and the data available for analysis, the initial data were selected for the calculation of the correlation of factors influencing the GDP of the agricultural sector (Table 1).

Conducting statistical calculations based on the data of factors affecting the GDP of the agricultural sector demonstrate that the development of the ICT industry in the country has a rather significant effect on the basic indicator (Table 2).

Table 1. Initial data for calculating the correlation of influencing factors on the GDP of the agricultural sector

Year	GDP agricultural sector, million UAH	The share of ICT in GDP, %	Lending, million UAH	Budgetary support, million UAH	Investments, million UAH	Production taxes, million UAH	Profitability, %
	y	x ₁	x ₂	x ₃	x ₄	x ₅	x ₆
2014	161 145	3.30	55 335	5 135	18 796	1 596	9.3
2015	239 806	3.64	48 425	4 143	30 154	3 078	30.5
2016	279 701	3.74	55 374	4 075	50 480	1 934	30.4
2017	303 419	3.70	59 706	10 532	64 234	2 677	25.6
2018	360 998	3.9	67 675	13 054	66 104	2 862	16.5
2019	356 563	4.59	61 600	13 020	58 555	2 921	14.2
2020	393 077	4.96	61 486	13 496	50 189	3 783	16.1
2021	593 367	4.69	82 600	12 800	49 127	4 206	40.3

Source: built by the authors based on State data Statistics Service of Ukraine (2023)

Table 2. Results of the statistical correlation analysis of factors influencing the GDP of the agricultural sector for 2016-2022

Year	y	x ₁	x ₂	x ₃	x ₄	x ₅	x ₆
2016	1						
2017	0.791226	1					
2018	0.908293	0.587056	1				
2019	0.722236	0.770969	0.712989	1			
2020	0.492585	0.413989	0.43013	0.687041	1		
2021	0.853102	0.815869	0.637284	0.67397	0.32218	1	
2022	0.519694	0.114487	0.346356	-0.13367	0.10044	0.442209	1

Source: "Excel data analysis" program

Regression statistics and variance analysis using the Excel Data Analysis package show: multiple R = 0.999753, R-squared = 0.999507, normalized R-squared = 0.996546, standard error 7520.138. The equation of dependence of agricultural GDP on the selected influencing factors is as follows:

$$Y = -550393.9 + 69258.5x_1 + 7.64x_2 - 6.57x_3 + 1.22x_4 + 36.68x_5 + 1417.68x_6, \quad (1)$$

where x_1 – the share of ITC in the total economic GDP, x_2 – agricultural lending, x_3 – budget support, x_4 – agricultural investments, x_5 – taxes on agricultural production, x_6 – profitability of activity.

Calculations show that the agricultural GDP is largely shaped by the factors presented in the model, according to the determination coefficient close to 1. The actual value of the Fisher criterion ($F_{\text{calculated}} = 337.57$) exceeds the critical value ($F_{\text{critical}} = 0.041$). The highest degree of dependence, and therefore influence on GDP growth, is attributed to the share of the digital economy. Following in descending order are profitability, tax incentives, financing, with

budgetary support showing a neutral impact. For a more precise analysis, deeper samples are needed for factors, with a much longer lag over the years, at least 15 years. However, statistical, and analytical data closed during the period of martial law postpone such analysis into the future. The ability to measure the impact of innovations on the GDP of the agricultural sector contributes to the selection of effective management decisions, prioritizing the funding of innovative development.

The imposition of martial law has redirected the economy exclusively towards the needs of national security and defence. State programs for financing innovations have nearly folded, either being carried out on a residual basis or on a grant basis with funds from Ukraine's partners. Legislative regulation of the development of research and innovation infrastructure during this period supports directions (programs): funding for scientific research, digital transformation of education and science, funding for strategic priorities (indicators by 2032), support for science from international partners, and so on. The funding of strategic priority areas of

innovation activity, “Technological renewal and development of the agro-industrial complex” in terms of technology development and implementation from 2020-2022 through budgetary funds, is provided in Table 3. Budgetary funding for strategic priorities in innovation

activity and technology transfer activity in Ukraine under priority 4, “Technological renewal and development of the agro-industrial complex,” among the seven medium-term priorities in 2022 amounted to 150.40 million UAH, or 71.7% of the 2021 level.

Table 3. Financing according to the direction “Technological renewal and development of the agro-industrial complex” in terms of the development and implementation of technologies in 2020-2022, UAH thousand

Program levels	In total			NAAS		
	2020	2021	2022	2020	2021	2022
4.1. production, preservation, and processing of high-quality plant products	92 916.04	106 501.97	81 519.82	87 437.00	102 059.93	67 435.82
4.2. adaptive soil conservation agriculture	34 034.69	40 765.32	25 922.33	3 315 600	19.07	25 583.63
4.3. the latest biotechnologies in plant breeding, animal husbandry and veterinary medicine	16 373.20	18 882.00	12 463.82	16 124.00	18 863.30	12 463.82
4.4. production of livestock and pig breeding products	13 091.57	15 087.37	99.66	12 701.00	14 892.03	9 839.86
4.5. creation of highly productive alternative sources for obtaining fuel	4 671.00	5 535.3	3 542.35	4 671.00	5 361.03	3 542.35
4.6. production of diagnostic kits for animal diseases and means of their protection	5 203.0	6 089.354	7 036.04	5 100.00	5 956.36	3 935.94
4.7. production of diagnostics of plant diseases	2 348.10	2 286.81	1 443.8	1 905.00	2 183.88	1 443.18
All according to medium-term priorities	168 638.3	195 148.5	141 854.4	16 109 400	188 035.6	124 244.6
All according to strategic priority	184 048.11	209 802.9	150 406.2	170 100.0	198 560.6	131 198.1

Notes: NAAS – National Academy of Agrarian Sciences of Ukraine

Source: data by T.V. Pisarenko *et al.* (2023)

The share of agriculture in total funding amounts to more than half (56.3%), which, according to the findings of T.V. Pisarenko *et al.* (2023), indicates the preservation of the agricultural sector's leadership among strategic priorities despite the slowdown in innovative activity. Funding is primarily provided by the funds of the National Academy of Agrarian Sciences (90.5%), as well as the Ministry of Education and Science of Ukraine.

Expenditures on research work in the field of economic sciences related to agricultural sciences during the period 2018-2023 averaged 1,400 million UAH per year. According to the Analytical Report “Implementation of Priority Directions in Science and Technology Development and Achieved Results in 2022” (Ministry of Education, 2023; Pisarenko *et al.*, 2023), government expenditures are the main source of funding, accounting for over 80% of the

funds. During the analysed period of 2018-2022, the funding structure was distributed as 84% state funds and 16% corporate or other sources. The lack of reporting on the innovation activities of industry enterprises does not allow for a more accurate tracking of the data proportion.

Law of Ukraine No. 2710-IX (2022, November) extends the previously active programs 2801050 “Scientific and scientific-technical activities in the development of the agro-industrial complex, standardization, and certification of agricultural products,” 2801130 “Qualification enhancement of specialists in the agro-industrial complex.” Funding for the scientific, technical, and educational components of agricultural programs from the State Budget for 2018-2023 and their share in the expenditures of the Ministry of Agrarian Policy and Food and in expenditures on science by economic sectors is presented in Table 4.

Table 4. Financing of the scientific, technical and educational component of agricultural programs of the State Budget in 2018-2023, UAH million

Programs	2023*		2022	2021	2020	2018
By functional classification						
Fundamental and applied research and development in the field of agriculture	1 956	2 006	1 483	823	1 368	1 367
Share in economics research, %	92.9	93.0	92.5	88.9	93.5	89.9

Table 4, Continued

Programs	2023*		2022	2021	2020	2018
By program classification						
MAPF apparatus	1 475	1 539	2 053	5 106	4 031	4 668
280105 Scientific and scientific and technical activity	112	126	110	151	161	186
2801130 Advanced training	30	36	27	28	23	22
Share of expenditures on science, education, %	9.63	8.57	6.67	3.50	4.56	4.45

Notes: * – planned indicators: plan/adjustment as of September 1, 2023

Source: Ministry of Finance (2023)

The scientific and educational expenses of the Ministry of Agrarian Policy and Food (MAPF) from 2018 to 2023 decreased by 22% in terms of funds, while their share in the agrarian budget increased from 4.45% in 2018 to 8.57% in 2023. This indicates a formal nature of funding and the actual cessation of state support. In particular, even in the initial version of the State Budget for 2023, expenditures for agricultural science and education were budgeted at 9.63%, but as of September 1, 2023, it was adjusted to 8.57%. The opportunities for budget financing of scientific and technical activities in the agricultural sector through MAPF programs are practically non-existent.

Assessing the potential for financing the innovative development of Ukraine's agricultural sector in the conditions of economic digitalization involves considering the financial resources that the sector can attract for innovation and innovative activities from corporations. In the current situation of a state of war and critical shortage of financial resources, financing from internal sources will be even more limited, as activities with zero profitability are considered successful. However, experts suggest that developed countries create favourable conditions for business investment in innovation using indirect tools such as deducting investments from the tax base, preferential tax rates and "tax holidays," credits and grants, accelerated depreciation of assets, exemptions from infrastructure fees and land rent, insurance of innovative exports, government procurement of innovations, and more (Pyvovarov, 2018).

Therefore, the problems of financing essentially boil down to the search for resources depending on their cost. Currently, the state and financial market of Ukraine lack sufficient instruments to support agro-innovations. More realistic sources are funds from Ukraine's foreign partners and international funds for partnership support. However, disruptions in domestic and external logistics of agricultural product distribution and the forced preference for certain channels, such as the so-called "grain corridor," do not encourage support for domestic farmers by simultaneously weakening the competitiveness of investor countries.

An analysis of the multitude of factors in innovative activities allowed the formulation of their main criteria, sources of funding, and peculiarities of implementation during a state of war. To complement the findings, it is advisable to analyse the recommendations of other researchers and identify conflicting aspects of the issue of financing agricultural innovations. R. Birner *et al.* (2020) provide a

classification of some financing business models and note that digital services (as part of innovation) can be provided to farmers, traders, and consumers for free or for a fee, through mobile network operators, donors, suppliers, and the government. Accordingly, the sustainability of financing will have variations: variable, relying on (un)stable support from network providers; reliable, if participants can obtain lower service costs than the regular price and ensure higher product quality. Here, it is crucial to ensure that marketing and data collection benefits outweigh the costs of providing them.

L. Hrustek (2020) established that the advantages of applying digital technologies, big data and analytics, the Internet of Things, artificial intelligence and machine learning, blockchain, and Cyber-F, along with improved business forms supported by digital technologies, contribute to achieving business goals, saving time and money, flexibility, and efficiency of business processes. For agriculture, the development of new advanced digital solutions is expected to adapt risk management to preserve biodiversity and environmental protection, ensure an adequate supply of quality food products, harmonize all economic, environmental, and social development goals of society. In turn, research by T. Sus *et al.* (2023) indicates that the collaboration of innovation market actors on a mutually beneficial basis will contribute to the implementation of the innovation development strategy of the agricultural sector, increase the competitiveness of agricultural products with high added value in international markets, and increase the export of science-intensive products and technologies.

Experts (What five areas for startups..., 2022) point out the sectors in which Ukrainian startups will have the highest demand for innovations: defence and cybersecurity, construction and infrastructure, healthcare and medicine, educational projects, the agricultural sector, and green technologies. Investors show particular interest in the agricultural sector, where technologies such as artificial intelligence, biotechnology, cloud solutions, big data analysis, and drones are applied. This also creates unique opportunities for "product startups" (FoodTech) that can occupy a more significant position in the Ukrainian IT market, which was previously mainly service-oriented and outsourcing. There is a growing demand for technologies for agriculture and "green" startups aimed at environmental conservation and combating climate change. These technologies contribute to the more efficient operation of the agricultural sector and sustainable development.

Therefore, in the scientific-expert environment, an expanded approach has been formed to assess the role and need for comprehensive funding of innovations, focusing on the needs of the entire ecosystem, including farmers, processors, resource producers, providers of financial services to the population, and governments. In such conditions, the resource will not be just data but newly created advanced algorithms and knowledge through which the management of agricultural processes will be concentrated on climate change and global warming in response to sharp weather changes and other disruptions in the economy. If the state supports this investor interest through fiscal methods, it can become one of the main sources of innovation funding. The essence of applying the approaches of global agricultural practice to innovation financing, considering the business resource, lies in the possibility and necessity of aligning competitive conditions for economic activities and preventing a monopoly on access to digital (and financial) resources. This allows complementing the formulated provisions regarding the sources of financing agricultural innovations in the conditions of the digital economy.

Thus, the discussion is implemented in a series of recommendations that complement the above based on the conducted analysis. Such an approach allows generalizing and expanding the already known list of sources of funding for researchers' developments (Pyvovarov, 2018; Sus *et al.*, 2023) and systematizing them by components:

- Self-financing through refinancing profits into innovative projects and products.
- State support as direct financing of science, research, development, and production from the budget and government-attracted foreign investments.

- Grant funding through attracting funds from domestic and foreign donors, participating in international and cross-border cooperation programs.

- Targeted loans in the form of credits from commercial banks, bond loans, leasing, factoring.

- Financial cooperation as financing based on the cooperation of finances and resources of various corporations: cooperative unions, all economic forms on the principles of mutual assistance.

- Innovative financing through crowdfunding, venture financing, listing shares on stock exchanges, etc.

The combination of these source options in the conditions of network interaction shows the advantages of financing within the financial cluster, as indicated by (Zarichna, 2021). This is important because the challenges of the time require equivalent measures for the development of the digital economy and the search for sources of its financing. Given the disruptions experienced by the agricultural sector and its logistics, post-war recovery is possible precisely through targeted efforts of the government, international partners of Ukraine, and agricultural corporations for innovative development based on the best global scenarios adapted to national needs for ensuring and guaranteeing food security. Now, researchers recommend forming clusters based on production and financial characteristics (Kovalenko *et al.*, 2023).

The scheme of the mechanism of the financial cluster for the needs of financing agricultural innovation development is presented in Figure 3. The mechanism of such a cluster is essentially institutional, connecting economic and social components and manifesting itself at the level of the state, financial market, sectors of the economy, agricultural corporations, and investors.

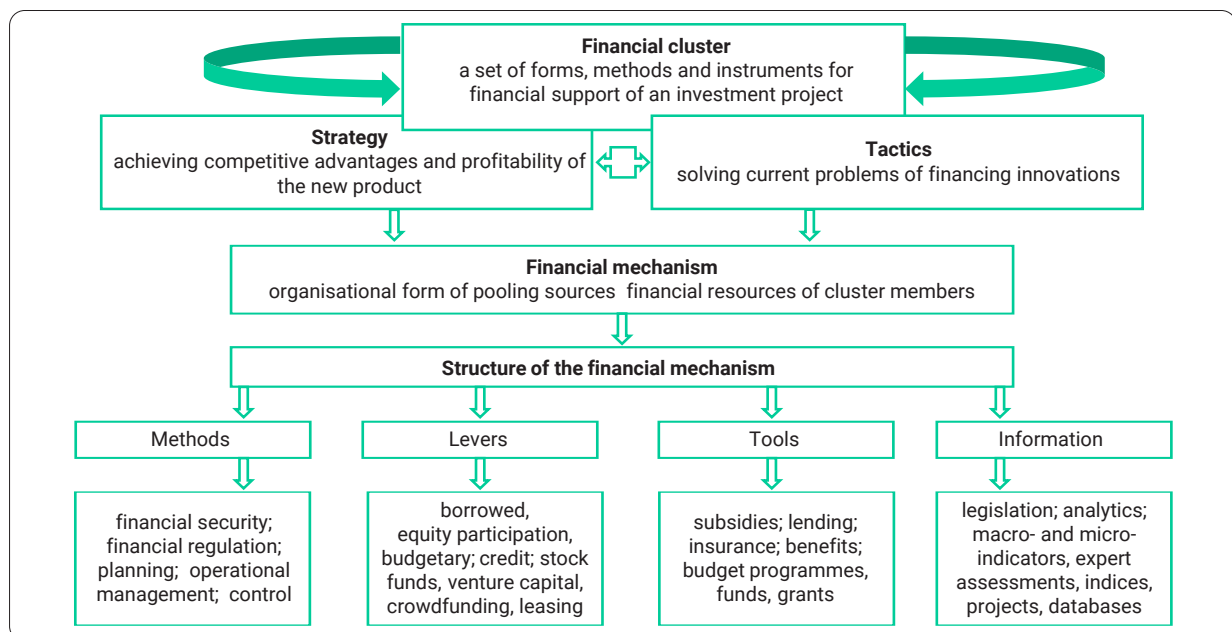


Figure 3. Scheme of the mechanism of the financial cluster of agrarian innovative development of Ukraine ranches of the economy of Ukraine for 2014-2022, UAH million, %

Source: developed by the authors based on N.Z. Zarichna (2021); T. Sus *et al.* (2023)

Therefore, considering the entire spectrum of problems discussed in the directions, it is to be noted that the optimal form of financing the innovative development of the agricultural sector at the present time is the consolidation of actors in the innovation market into a financial cluster. It will play the role of generating and implementing forms, methods, and instruments of financial support for the implementation of an investment project for the benefit of all participants and the multiplier effect on the sustainable development of agriculture. The cluster's mechanism of action involves a set of organizational, regulatory, and managerial measures to support the balance of financial resources of corporations and the industry to optimize financial flows (redistribution of financial resources) for the needs of innovation and/or innovative activities. Such a financial cluster is realized within the financial market and has methods and levers corresponding to the current regulatory framework. The special product of the financial cluster is its characteristic financial instruments, which depend on the contours of the form or method of the contract/agreement used to attract financial resources. This allows the government and entities in the agricultural sector to expand sources of investment with mutual benefit and to control market providers, preventing them from having the right to monopolize the provision of financial resources for digital technologies exclusively in a consumer-oriented context.

Conclusions

This study demonstrates that innovative development in the agricultural sector is crucial for overcoming destructive trends in the conditions of war and post-war recovery. The issue of finding relevant sources of funding is particularly relevant. The Global Innovation Index for Ukraine from 2014 to 2022 fluctuates over the years, but has changed very insignificantly, from 63 to 57, although there is a moderate trend towards strengthening positions, especially in components such as human capital, business environment, knowledge, and quantitative research results (Krykova et al., 2021). It is likely that to overcome the economic decline during periods of armed conflict, it is necessary to boost innovative activities to the level of countries that have experienced armed conflicts and successfully recovered from devastation.

The dynamics of GDP volumes and the share of individual sectors in Ukraine from 2014 to 2022 indicate that the decline in the GDP of the agricultural sector is deeper than that of the digital sector, 28% compared to 7%. Probably, increasing the share of digital services in the formation of agricultural GDP will contribute to sustainable growth. Since the decline in the volumes of the agricultural sector in the wartime of 2022 compared to 2021 was, If the pre-war level of government spending on financing agricultural innovations in terms of their development and dissemination accounted for about 80.2% of research funding in the

economy, which is clearly insufficient for the simple reproduction of the formation of scientific products, then even the preserved 92.8% funding for budget expenditures on scientific research during the wartime will not produce the expected effect. Evidence of this is also the fact that the share of MAPF expenditures on science and education has decreased by 22% over the past 6 years, although by structure, it has increased from 4.45% in 2018 to 8.57% in 2023, which is explained by the reduction in overall financing of the agricultural sector by 67% during this period.

An assessment of the state of financing in the agricultural sector aimed at enhancing innovative processes in the post-war period has been carried out. This assessment is based on a systemic approach to the formation of financial resources for the implementation of innovations. A dependency on the growth of the agricultural GDP from several factors has been identified based on correlation and variance analysis. The correlation results show the highest impact from the growth of the ICT share in the economic structure, followed by profitability, tax incentives, financing, and budgetary support, which has almost no influence due to minimal amounts. The possibility of measuring the impact of innovations on the GDP of the agricultural sector contributes to the selection of effective management decisions in prioritizing the financing of innovative development.

It has been established that financing the agricultural sector to promote innovative processes during periods of crisis should be based on a systemic approach. This approach is rooted in a financial cluster mechanism that considers the interests of all participants in the process. The variability of financing depends on the possibilities of implementing digital directions in the production and operational activities of farmers, filling the state budget, and generating international aid or financing. The sources of financing depend on the chosen agricultural policy, but most remain traditional: self-financing, state support, grant funding, targeted loans, financial cooperation, innovative financing, and so on. Importantly, the criterion for agricultural investment should be societal interest in achieving sustainable development goals, environmental friendliness of activities, cost reduction of production factors, and improvement of the quality of financial and human capital.

Further research directions include addressing issues related to the diversification of financial support for innovative development to effectively choose sources of financial resources for implementing innovative processes in the agricultural sector.

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Conflict of Interest

None.

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Фінансування інновацій аграрної галузі як складової цифрового розвитку економіки України

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Анотація. Інноваційний розвиток економіки є умовою стабільного зростання, що для аграрної сфери має особливе значення, виводячи управління біологічними активами на суттєво вищий рівень. Мета роботи полягає у визначенні потенціалу інноваційного розвитку аграрної галузі України та дослідженні особливостей її фінансування. Застосовано загальнонаукові методи, герменевтичний метод; статистичний і кореляційний для виявлення зв'язку факторів впливу; табличний та графічний для презентації результатів; узагальнення для висновків. Оцінено позиції України за Глобальним Індексом Інновацій (2014-2022 рр.) який досить низький і знизився за період з 63 до 57, але має потенціал за складовими людського капіталу, бізнес середовища, наукових досліджень. Виявлено залежність зростання обсягів аграрного ВВП від ряду факторів на основі кореляційного та дисперсійного аналізу, зокрема й за рахунок нарощування інновацій. Структура динаміки ВВП показує спад аграрної галузі у воєнному 2022 році проти 2021 року на 28 %, а інформаційно-телекомунікаційної галузі – лише на 7 %. Якщо довоєнний рівень державних видатків на фінансування аграрних інновацій сягав 80 % загальноекономічних, що забезпечувало лише відтворення умов формування наукоємної продукції, то навіть підвищення його до 90 % у період воєнного стану не покриває реальних потреб. Науково-освітні видатки Міністерства аграрної політики і продовольства у 2018-2023 рр. за обсягом коштів знизились на 22 % за період, а їх частка зросла з 4,45 % у 2018 році до 8,57 % у 2023 році, через падіння загального рівня фінансування на 67 %. На підставі оцінки стану фінансування інновацій аграрної галузі з метою їх нарощування запропоновано системний підхід до вибору джерел фінансування. Побудовано оптимальну схему фінансування аграрних інновацій за консолідованими джерелами за умов формування фінансового кластеру. Практичне значення дослідження полягає у можливості використання його результатів при розробці стратегії поствоєнного відновлення аграрної галузі в частині оцінювання ефективності моделей фінансового забезпечення інноваційного розвитку

Ключові слова: джерела фінансування; наукове забезпечення; бюджет; цифровізація; фінансовий кластер