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The role of innovative entrepreneurship in the modernisation of agricultural enterprises in Ukraine

Abstract. The purpose of this study was to substantiate the role of innovative entrepreneurship in increasing the efficiency and financial sustainability of agricultural enterprises in Ukraine in the context of military and macroeconomic challenges. The research methodology was based on an empirical approach using structural-logical, comparative-dynamic, statistical-dynamic, interval, descriptive, trend, technological-functional, and institutional-comparative analysis, generalising analysis of sources and case studies of the activities of an agricultural enterprise. The results of the study showed an increase in the share of innovatively active agricultural enterprises from 6.2-6.5% in 2020 to 7-8% in 2024-2025, despite the reduction in total capital investments in 2022. It was found that fuel level trackers and machine condition monitoring systems were used in approximately 70% of farms, while linear navigation and field dynamics analysis systems

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were used in about 60%. In 2021-2023, about 3.1 million hectares were processed using drones, and in 2024-2025 – up to 1 million hectares annually. Differentiated input of resources ensured an increase in yield by 4-22%. Analysis of the activities of Myronivsky Hliboproduct showed the restoration of operating margins to 11-12% and an increase in earnings before interest, taxes, depreciation and amortisation to 16-17% in 2023-2024. Comparison with Poland, Slovakia, Hungary and Romania showed that in these countries 5-10% of the funds of the second pillar of the Common Agricultural Policy of the European Union are directed to innovative areas with a level of development of 70-85%, which ensures an increase in productivity by 15-30% and profitability by 20-40%. The practical significance of the study lies in the possibility of using its results by agricultural enterprises to justify decisions on the implementation of innovations

Keywords: technological renewal; agribusiness; innovation activity; investment; transformations; resilience

INTRODUCTION

Structural changes in the Ukrainian economy are deepening due to wartime challenges, global instability and the transformation of agri-food markets. This brings the task of updating the production and management models of agricultural enterprises to the forefront. In conditions of limited access to capital, rising costs, logistical disruptions and heightened risks, the effectiveness of traditional development mechanisms is diminishing, intensifying the need for entrepreneurial approaches that focus on implementing new technologies, business solutions and organisational practices. Low resource efficiency, significant volumes of unrealised by-products, and dependence on linear resource use models constrain the renewal of production and management processes, reducing the economic resilience of enterprises. V. Shebanin *et al.* (2024) analysed these issues, examining the implementation of circular economy principles as a tool for reducing costs, increasing profitability, and strengthening socio-economic effects through the reuse of resources, the development of bioenergy solutions, and the formation of closed production cycles. Their results demonstrated that applying circular approaches optimises material and energy resources, creates additional employment and improves the performance of agricultural enterprises.

The instability of the economic environment, caused by wartime risks, inflationary pressures, and fluctuations in resource prices, makes long-term planning and investment activity difficult, as well as hindering the reproduction of the production potential of agricultural enterprises at the regional level. O. Khrystenko *et al.* (2025) used regression analysis, econometric modelling and a scenario approach to forecast the development of the agricultural sector under conditions of economic instability. Their study revealed crop yields, the structure of sown areas and investment activity to be highly sensitive to changes in macroeconomic factors, particularly inflation levels and fuel prices. It also revealed a limited potential for production recovery under unfavourable scenarios. A.S. Poltorak *et al.* (2023) examined the relationships between food security indicators. Based on a correlation-regression analysis of data from 113 countries, they demonstrated a statistically significant correlation between the economic accessibility of food and the extent to which agricultural production adheres to sustainable development principles. The results showed that in countries with high purchasing power, these relationships are stable and economically significant. However, under medium and low levels of food accessibility, they lose statistical strength, which limits the possibility of universally applying such models.

The fragmented implementation of innovations, the weak integration of technological, organisational, and socio-economic solutions, and the limited coherence between improving production efficiency and enhancing the development conditions of rural areas, constrain the comprehensive renewal of agricultural enterprises. V. Mamchur & G. Studinska (2023) focused on forming a model of innovative development within the national resilience system.

They substantiated the need to combine technological, institutional, organisational, and marketing innovations to increase productivity, expand value chains, strengthen export potential, and improve socio-economic living conditions. Their results showed that systematically implementing a package of innovations can ensure a synergistic effect on economic performance and sustainable development. They also emphasised the role of state reforms and institutional prerequisites in initiating such changes. However, low innovation activity, the predominance of imitative technological solutions, and dependence on imported equipment limit improvements in productivity, competitiveness, and the sustainability of agricultural enterprises. Against this backdrop, V.V. Antoshchenkova & M.O. Peresada (2023) emphasised the pivotal role of innovation in agricultural production. They substantiated the impact of technological advancements, mechanisation, and biotechnological solutions on enhancing crop yields, improving resource efficiency, and transforming production models. Notably, they examined these aspects through the lens of Cochrane's "treadmill" theory. The study demonstrated that, while innovations contribute to growth in labour productivity and economic performance, they also generate risks of overproduction, price pressure and the displacement of small producers when development is primarily oriented towards scale and price. N. Kovalenko & Y. Malakhova (2025) focused on the strategic management of innovation activity. They substantiated the need to form an organisational-economic mechanism that combines the assessment of innovation potential, the definition of an innovation strategy, and phased control over the results of its implementation. Their analysis confirmed that integrating strategic management and innovation processes has a positive impact on productivity, cost efficiency, and the competitiveness of enterprises in times of economic instability.

Entrepreneurial activity develops under conditions of complex interaction between formal and informal institutions, unequal access to financial and organisational resources, and increased sensitivity to macroeconomic and social transformations. I. Deineha *et al.* (2021) examined these issues, focusing on analysing the institutional environment for small and medium-sized enterprises. The authors concluded that the effectiveness of entrepreneurial activity is determined by the quality of state regulation, the availability of financial support instruments, the coherence of institutional mechanisms, and the stability of economic rules. T. Sus *et al.* (2023) classified financial models to ensure innovative development. They analysed combinations of self-financing, budgetary support, cluster and cooperative mechanisms. They also proposed a methodology to assess the influence of financing on regional innovation potential. The results obtained demonstrated differentiation among regions according to the level of financial support for innovation, as well as the dependence of innovation activity on the structure of attracted resources.

Meanwhile, existing studies have primarily focused on macro-level environmental and methodological aspects. However, the entrepreneurial mechanisms for initiating, scaling and commercialising innovations, and their impact on modernising business and management models in the agricultural sector, remain insufficiently explored. This study aimed to determine the influence of innovative entrepreneurship on updating production and management processes in Ukrainian agricultural enterprises. To this end, two objectives were set: to analyse the implementation of digital, technological and organisational innovations in Ukrainian agricultural enterprises between 2020 and 2025; and to evaluate the effect of innovative entrepreneurship on production performance indicators, crop yields and the financial resilience of Ukrainian agricultural enterprises.

MATERIALS AND METHODS

This empirical study aimed to analyse the dynamics of innovative and economic processes in Ukrainian agricultural enterprises between 2020 and 2025. This time period was chosen due to the intensification of digitalisation in the agricultural sector and changes in operating conditions after 2022, enabling dynamic analysis. To evaluate the structure of implemented innovations and the level of automation of production processes, a structural-logical analysis of data from Yu. Makovey (2025) on the application

of Agriculture 4.0 approaches in Ukrainian agricultural enterprises was used. This made it possible to categorise the use of drones, Global Positioning System (GPS) satellite navigation systems, automated data collection systems, and digital platforms for managing production operations, and to determine their role in the production cycle.

A comparative-dynamic approach was used to study the volumes of state, concessional and grant funds directed towards innovation in the agricultural sector, with a particular focus on the implementation of state support programmes. The credit programme "5-7-9%", which financed investment and modernisation projects for agricultural enterprises in 2020-2025, was examined in detail. Sources used included V. Khvorostyaniy (2020) and State Support for Farmers in 2025 (2024). The dynamics of capital investment in Ukrainian agriculture and the proportion of investment directed towards innovation between 2020 and 2025 were examined using statistical and dynamic analyses, as well as interval analyses of indicators of total capital investment and investment in innovation, and their respective shares in the financing structure. These analyses were based on secondary sources such as Investments in the Agricultural Sector of Ukraine (n.d.) and S.Yu. Sokoliuk *et al.* (2025). This approach identified structural shifts in the investment priorities of agricultural enterprises during a period of limited access to capital.

The practices of differentiated fertiliser application, the use of drones, and precision approaches in crop production were studied using a technological-functional approach. A comparative assessment of the level of automation of production operations was carried out based on the Ukraine Digitalisation Index (2025) and V. Polishchuk (2025). This made it possible to establish a relationship between digital technologies and the efficiency of agrotechnological processes. To evaluate the outcomes of production during the implementation of digital solutions, a descriptive analysis of crop harvesting indicators in 2025 was conducted (Ukraine completed the harvest..., 2025). The impact of innovative entrepreneurship on the performance of agricultural enterprises was assessed economically using a case study of Myronivsky Hliboproduct (MHP), which was selected as a representative example due to the scale of its production activities, the systemic nature of innovation implementation, and the availability of open financial and operational information (MHP SE, 2024; 2025). The analysis examined the full-scale implementation of precision farming and the introduction of the innovative "Biogas 5.0" programme, which aims to decarbonise production, utilise by-products, and form closed energy-resource cycles. This enabled the economic impact of innovation on the enterprise's production and financial activities to be evaluated (MHP innovation programme, 2021).

The integration of artificial intelligence into production and management processes was analysed using a functional-analytical approach, illustrated by MHP's transition to the SAP S/4HANA Enterprise Resource Planning (ERP) platform and the introduction of digital ecosystems for personnel and business process management, Myronivsky Hliboproduct for You (MHP4U, n.d.). This made it possible to evaluate the impact on controllability, analytical decision support, and operational efficiency. The economic impact of the innovation in 2025 was evaluated through statistical analysis of crop production results, focusing on yield and harvest volume indicators presented in MHP received a record... (2025). This analysis revealed the impact of technological solutions on enterprise productivity. The financial performance of innovative entrepreneurship was examined through a dynamic financial analysis of revenue, operating profit, adjusted EBITDA, and margin levels from 2020 to 2025, based on official financial reports from MHP SE (2024 and 2025). This analysis revealed changes in the enterprise's financial resilience over time. Trend analysis of financial indicators in the post-shock period (2023-2025) was carried out using data from the official financial reports "Financial results for the first quarter ended 31 March 2025" and "Unaudited financial results for the first quarter ended 31 March 2024", identifying changes in operational efficiency and profitability under conditions of digitalisation and automation of management processes.

A comparative analysis was carried out using institutional-comparative and structural

analyses to examine innovative approaches to the modernisation of agricultural enterprises in Ukraine and neighbouring European Union countries (Poland, Slovakia, Hungary and Romania). The analysis was conducted according to the following criteria: land-use structure, the level of innovation activity within agricultural enterprises, and access to financial resources. The countries were selected due to their proximity to Ukraine, similar natural and climatic conditions, and participation in the Common Agricultural Policy (CAP) (Agriculture and Rural Development, n.d.). The analysis was conducted using data from Eurostat (2022) and M. Teryukhanova (2025). The institutional conditions for developing innovative entrepreneurship were evaluated by analysing the European Union's Common Agricultural Policy, particularly its second pillar, Pillar II (Rural Development), and the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI) mechanism. This made it possible to determine the role of supranational instruments in stimulating innovation. In the case of Ukraine, national programmes supporting innovative entrepreneurship in the agricultural sector were analysed, including the "5-7-9%" preferential credit programme, as well as the eRobota (n.d.) and Own Business... (2025) grant instruments. International initiatives were also examined, including the USAID Agricultural and Rural Development Programme and the Food and Agriculture Organization of the United Nations (FAO) programme. Analysing these programmes made it possible to evaluate how agricultural enterprises in Ukraine access financial resources, innovation instruments and technological support, and how this compares with the mechanisms operating within the European Union's Common Agricultural Policy.

A comparative index approach based on data from E. Francica (2025) was used to analyse the level of innovation among agricultural enterprises in EU border countries, which made it possible to identify their position within the structure of innovation development in the European Union. The economic impact of innovative entrepreneurship and the influence of the EU's environmental policies were evaluated through an analysis of generalising empirical studies and strategic documents, such as the European Green Deal and Farm to Fork. This allowed for comparing entrepreneurial incentives, regulatory constraints, and innovation outcomes in the agricultural sector, using data from V. Choudhary *et al.* (2025) and I. Tomashuk *et al.* (2025).

RESULTS

Analytical characteristics of innovation and modernisation processes in agricultural enterprises in Ukraine

From 2020 to 2025, the innovation activity of Ukrainian agricultural enterprises developed amid limited access to financial resources, wartime risks, and shifting investment priorities. This resulted in a gradual increase in the proportion of entities engaged in innovation. The proportion of enterprises introducing innovations increased from 6.2-6.5% in 2020 to 7-8% in 2024-2025 (Kalina *et al.*, 2025). This trend was primarily driven by digital and technological solutions aimed at optimising costs, improving the precision of production operations, and adapting production to labour shortages. Within the structure of implemented innovations, elements of precision agriculture predominated, particularly the use of drones, GPS satellite navigation systems and automated data collection and processing. However, the number of agricultural enterprises using drones and automated solutions remained largely confined to large farms, accounting for around 10-12% as of 2025. Meanwhile, the actual scale of use of such technologies remained stable: approximately 3.1 million hectares were treated with drones in 2021-2023, whereas the area treated was estimated at up to 1 million hectares annually in 2024-2025 (Makovey, 2025). This reflects the concentration of innovative technology use in enterprises with large land holdings and greater investment capacity.

The automation of production processes and the use of artificial intelligence tools were selective in nature. Around 12% of agricultural enterprises used algorithms for fertiliser application planning and yield forecasting. By contrast, auxiliary digital solutions became more widespread, with fuel level trackers and systems for monitoring the location and technical condition of machinery being used on around

70% of farms and linear navigation systems and field dynamics analysis systems being applied on around 60%. Automatic sprayers (used by around 34% of enterprises) and Real-Time Kinematic (RTK) high-precision positioning technologies (used by around 52%) remained less widespread, due to the high investment required for such solutions (Makovey, 2025).

The volume of state, concessional and grant funding directed towards innovation in the agricultural sector fluctuated unevenly between 2020 and 2025. In 2020, the total amounted to around UAH 4.0 billion, which was used to compensate for the cost of machinery and to develop horticulture and livestock farming (Khvorostyaniy, 2020). In 2021, funding increased to UAH 5.0 billion due to the expansion of the "5-7-9%" credit programme (PrivatBank, n.d.). In 2022, support declined to UAH 4.5 billion, with funding being reallocated to cover wartime risks and land demining. In 2023, funding increased to UAH 5.4 billion, with approximately UAH 1.5 billion directed towards stimulating private investment in modernisation. In 2024, funding reached UAH 6.0 billion, with a focus on developing irrigation systems and providing grants for greenhouse projects. In 2025, funding was estimated to be between UAH 4.7 and 6.0 billion, including per-hectare subsidies and financing for demining and land reclamation (State support for farmers in 2025, 2024). Figure 1 presents the dynamics of capital investment in Ukraine's agriculture and the share of funds directed towards innovative technologies in 2020-2025.

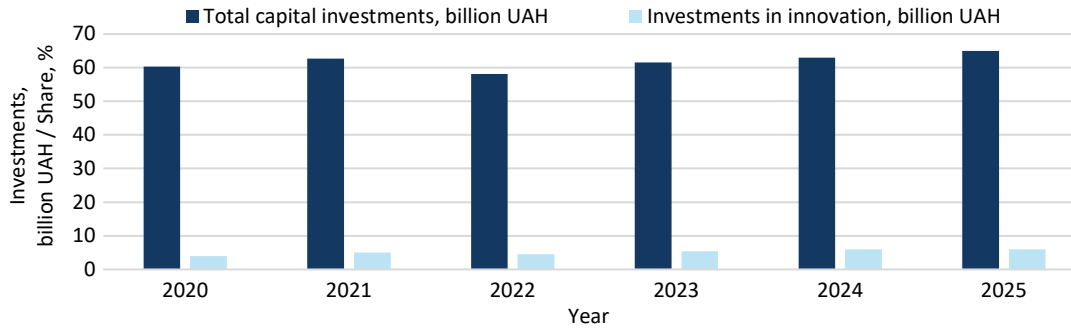

Figure 1. Dynamics of capital investment in Ukraine's agriculture and the share of investment directed towards innovation in 2020-2025

Source: compiled by the authors based on S.Yu. Sokoliuk *et al.* (2025), Investments in the agricultural sector of Ukraine (n.d.)

According to the presented data, the highest total capital investment volume was recorded in 2021 (UAH 62.7 billion), while the lowest was observed in 2022 (UAH 58.1 billion). The maximum share of investment in innovation was recorded in 2024 (9.5%), while the minimum was in 2020 (6.6%). The concentration of minimum values in 2022, followed by an increase in the share of innovation investment up to 2025, indicates a shift in the investment priorities of agricultural enterprises towards technological renewal, despite limited recovery in the overall volume of capital investment. From 2020 to 2025, wartime restrictions, climatic fluctuations and accelerated digitalisation transformed the structure of production operations in Ukrainian agricultural enterprises, as reflected in changes to soil cultivation, sowing, fertiliser application and harvest organisation technologies, and a gradual shift in the balance between manual and machine-automated operations. In soil cultivation, the transition from traditional ploughing to mini-till, no-till and strip-till systems was driven by the need to retain moisture, reduce erosion and cut fuel costs. Technologically, this was accompanied by the increased use of combined units and wide-span machinery, reducing the number of fields passes and improving resource efficiency. The partial automation of tillage operations mainly occurred through the use of GPS navigation during chisel ploughing and discing, covering approximately half of the cultivated area

in large enterprises. However, full automation remained limited due to the high investment required for the necessary technology (Khablak & Arakelyan, 2021).

From 2020 to 2025, fertiliser application shifted from mass to localised application with variable rates, based on precision agriculture tools and algorithmic recommendations. By 2025, mineral fertiliser consumption had increased by 20% compared to 2024, reaching 3.42 million tonnes over eight months. This was accompanied by an increasing emphasis on differentiated application. Automation of fertiliser and crop protection product application was one of the most advanced areas of technological development: sectional application and variable rates were employed by around 78% of innovative farms (Polishchuk, 2025). The use of drones and spot-treatment approaches improved operational precision; however, the extent to which they were adopted differed substantially depending on enterprise scale and technological equipment. Automatic sprayers with advanced analytical functions were adopted less widely (by around 40-50% of enterprises), while autonomous, operator-free machinery remained largely at the pilot project stage in large companies (10-20%) (Ukraine Digitalisation Index, 2025).

Despite constraints related to security and the accessibility of certain land plots, harvesting in 2025 ensured production volumes of 57.6 million tonnes of cereals and 17.3 million tonnes of oilseeds, with an average cereal yield of 5.08 t/ha. The use of telemetry and machinery monitoring systems within the structure of harvesting operations expanded to approximately 70% of large farms, making it possible to control work execution, fuel consumption and machine operating modes while reducing response time to process deviations. The trajectory of modernisation was uneven over the years: in 2023, precision agriculture solutions accounted for around 22% of the market, while algorithms for fertiliser application planning accounted for around 12%. In 2024, 70-80% of innovative enterprises automated key production processes such as sowing, applying inputs and harvesting. In 2025, leading companies such as Kernel (n.d.) and UkrLandFarming (n.d.) had automated over 80% of their operations through the use of RTK navigation, telematics, drones and analytical platforms (Ukraine completed the harvest..., 2025). In summary, the structural changes in the production operations of Ukrainian agricultural enterprises between 2020 and 2025 manifested as a technological shift towards resource-saving tillage systems, an increased share of highly precise sowing and material input application, a stronger role for telemetry in harvesting processes and clear differentiation in the pace of modernisation between enterprises of different sizes and investment capacities.

Economic assessment of the impact of innovative entrepreneurship on the performance of agricultural enterprises

From 2020 to 2025, the implementation of innovative entrepreneurial solutions in Ukrainian agricultural enterprises was accompanied by noticeable changes in production and financial performance indicators. These solutions included elements of precision agriculture, automated technological processes, and digital production management tools, primarily used by large farms and, to a lesser extent, medium-sized ones. One of the key channels through which innovation exerted economic influence was crop yield. Using agrochemical soil analysis, field zoning, satellite monitoring and differentiated input application rates ensured yield increases ranging from 4% to 22%, depending on the crop and regional conditions. At Industrial Milk Company (IMC), for example, the average maize yield in 2021 was 10.55 t/ha, compared to an average of 7.42 t/ha in Ukraine, reflecting differences in nutrient management and technological operations. In 2025, more than 81 thousand tonnes of sunflower were harvested from 24.8 thousand hectares, yielding 3.3 t/ha; meanwhile, the average sunflower yield in Ukraine was 1.83 t/ha (IMC, n.d.).

Between 2020 and 2025, agricultural holding company MHP implemented an innovative entrepreneurial model, in which digitalising production and management processes became a key instrument for ensuring operational resilience and financial performance (MHP SE, 2024; 2025). Rather than being integrated as separate technological projects, innovations were incorporated as a component of the business model,

directly influencing the cost structure, profitability, and the company's ability to adapt to external shocks. The central element of MHP's innovative transformation was the large-scale adoption of precision agriculture. All cultivated land was mapped digitally, and electronic field maps, records of agrotechnological operations, yield indicators and agrochemical soil condition data were created. As part of its sustainable development strategy, MHP began introducing the innovative "Biogas 5.0" programme in 2020, which is aimed at decarbonising production and achieving carbon neutrality. This programme integrates biogas and biomethane technologies with systems for utilising organic waste, producing renewable energy and organic fertiliser, and reducing greenhouse gas emissions. MHP began implementing biogas projects before the introduction of the European Green Deal, establishing industrial biogas complexes to partially supply energy to the company's agro-industrial facilities. The transition to the "Biogas 5.0" concept also involves developing biomethane production technologies and integrating green hydrogen solutions. This creates a closed energy-resource cycle and expands the company's opportunities to participate in European climate and energy markets (MHP innovation programme, 2021).

From 2020 to 2025, MHP consistently integrated artificial intelligence (AI) tools into its production and management processes as part of its innovative entrepreneurial approach and digital transformation strategy. According to management estimates, investments in AI projects reached the break-even point during the implementation period of 2020-2021: the net economic effect in 2024 was in the region of hundreds of thousands of US dollars, and the expected effect in 2025 exceeded USD 1 million. The digital transformation of management, particularly the transition to the SAP S/4HANA ERP platform (Business Evolution, n.d.), formed the institutional basis for scaling AI solutions and ensured the standardisation of financial, production, logistics and sales processes. In 2024, MHP's investment in innovation exceeded UAH 900 million, one of the highest figures among Ukrainian companies. The implementation of digital projects was carried out by a team of around 350 specialists. Practical applications of AI included optimising poultry production by analysing large volumes of production data, automating climate control in poultry houses and forecasting crop yields. These solutions ensured lower operating costs and improved resource efficiency, enabling the company to achieve measurable financial results despite high levels of macroeconomic and wartime uncertainty (MHP innovation programme, 2021).

In developing the company's information technologies and digital ecosystems, one of the key steps was creating and implementing proprietary technological solutions adapted to the specifics of the agricultural and food business. These solutions include the Smart Technology Assistant (Smart TA), an adaptive system that supports decision-making in poultry farming at every stage of the production cycle, from planning to the automated control of essential rearing factors. Another example is the Data Model for Meat Processing (DMMP), an artificial intelligence-based model designed to optimise meat yield from specific anatomical parts of poultry and improve the consistency of quality indicators for finished products. As part of the digital transformation, the MHP4U (n.d.) recruitment ecosystem was also developed. This integrated various digital platforms and data analysis tools to manage the processes of attracting, selecting and developing personnel. Using these solutions ensured greater coherence between production and management processes, reduced transaction costs, and minimised the impact of human error, thereby increasing the company's operational efficiency (Lopokha, 2025). The economic effect of innovation in crop production was reflected in higher yield indicators. In the 2025 season, MHP harvested over 2 million tonnes of produce from a 330,000-hectare area, accounting for over 90% of the planned area. Wheat yield reached 7.7 t/ha, compared to 7.2 t/ha in 2024. Projected maize yield was estimated at 8.7 t/ha and sunflower yield at around 3 t/ha. These results demonstrate the maintenance of high productivity despite wartime risks and restricted access to some land (MHP received a record...., 2025).

The financial results of the MHP agricultural holding were achieved amid high levels of

macroeconomic and operational uncertainty, resulting from the impact of the pandemic, the war in Ukraine, logistical constraints and currency fluctuations. In this context, investments in digitalisation, production process automation and analytical management platforms were incorporated into the company's operational model as part of the transition to a "digital agricultural holding". To assess the economic impact of innovative entrepreneurship at MHP, the dynamics of key financial indicators in the first quarter of 2020-2025 was analysed (Table 1).

Table 1. Dynamics of MHP's key financial indicators in 2020-2025 (Q1)

Indicator	Years						Growth rate	
	2020	2021	2022	2023	2024	2025	2025/2020, %	2025/2024, %
Revenue, USD million	443	436	553	746	719	779	75.8	8
Gross margin, %	21	19	16	19	24	–	–	–
Operating profit, USD million	47	50	9	84	84	60	27.7	-28.6
Operating margin, %	11	11	2	11	12	8	-27.3	-33.3
Adjusted EBITDA (net of IFRS 16), USD million	90	83	43	117	119	111	23.3	-6.7
EBITDA margin (net of IFRS 16), %	20	19	8	16	17	14	-30.0	-17.6
Net profit/(loss), USD million	-174	33	-108	49	16	32	–	100
Net margin, %	-39	8	-20	7	2	–	–	–
Wartime costs, USD million	–	–	26	6	10	–	–	–
Share of export revenue, %	–	–	–	70	63	–	–	–

Source: compiled by the authors based on MHP SE (2024; 2025)

As shown in Table 1, 2021 was characterised by relatively stable financial parameters in MHP's operations. The operating margin was 11%, the EBITDA margin was 19%, and the net margin was 8%. These values can be considered the baseline level of performance for an innovation-oriented agricultural model under wartime-free conditions. The highest revenue volume during the analysed period was recorded in 2025 at USD 779 million, exceeding the 2020 figure by 75.8% and the 2024 figure by 8%. Meanwhile, the maximum gross margin (24%) and adjusted EBITDA (USD 119 million) values were observed in 2024, reflecting the peak of recovery in operational efficiency after the crisis period. However, in 2022, there was a sharp deterioration in financial indicators: the operating margin fell to 2%, the lowest value for the period, the EBITDA margin declined to 8%, and the net financial result became negative at USD -108 million. The lowest profitability indicators and a substantial reduction in earnings were precisely recorded in 2022, reflecting the impact of wartime costs (USD 26 million), foreign exchange losses and disruptions to production and logistics processes. From 2023 to 2024, MHP demonstrated an improvement in operational efficiency, with operating profit rising to USD 84 million and EBITDA increasing to USD 117-119 million. Net profit in 2025 amounted to USD 32 million, double the 2024 figure. However, a decline in the operating margin to 8% (-33.3% compared to 2024) and a reduction in the EBITDA margin to 14% were also recorded in 2025, indicating weakening margins despite maintained overall revenue growth. Thus, the dynamics of the indicators for 2020-2025 reflect a significant downturn in 2022, which was the lowest point of the financial cycle. This was followed by a recovery in 2024-2025, during which the highest revenue and profitability values were achieved. Comparing 2021 with the period 2023-2025 confirms that, after the wartime shock of 2022, innovative entrepreneurship at MHP acted as an economic stabiliser, ensuring the recovery of profitability and revenues, and maintaining financial resilience.

From 2020 to 2025, innovative entrepreneurship played a role in modernising agricultural enterprises in Ukraine. Implementing precision agriculture, automating production operations and introducing digital management systems increased productivity, made more efficient use of resources and enabled more controllable production processes. These changes

were most evident in large agricultural companies, where innovations were integrated into the business model rather than implemented as isolated technological solutions. The case of the MHP agricultural holding showed that systematic digitalisation and automation enabled production and financial resilience to be preserved under wartime and macroeconomic constraints. Innovative entrepreneurial solutions acted as an adaptive mechanism, ensuring the recovery of operational efficiency and stabilising financial results after external shocks. Overall, innovation in the agricultural sector not only raised productivity, but also became an element of enterprises' long-term economic resilience.

Comparative analysis of innovative approaches to the modernisation of agricultural enterprises in Ukraine and EU neighbouring countries

The European Union's border countries – Poland, Slovakia, Hungary and Romania – directly border Ukraine to the west and south. The border lengths are 542 km with Poland, 98 km with Slovakia, 137 km with Hungary and 614 km with Romania. Following the Union's enlargement, these borders became part of the EU's external frontier. The agricultural sectors of these countries are characterised by fragmented land use, family farming and the consolidation of land among medium and large-scale producers. In such circumstances, innovative entrepreneurship serves as a means of not only increasing productivity, but also of adapting agricultural enterprises to the EU's environmental, technological, and market requirements (Teryukhanova, 2025).

The land-use structure in EU border countries influences the pace and character of innovation implementation. In Romania, for example, over 90% of farms have an area of less than 5 hectares, whereas in Hungary it is around 65%. In Poland and the Baltic States, meanwhile, it is small and medium-sized family farms that predominate. Conversely, in Slovakia and in parts of Poland and Romania, large farms control between 50% and over 90% of agricultural land (Eurostat, 2022). This asymmetry leads to differing access to financial resources, technologies and knowledge, shaping the dual nature of innovative entrepreneurship: large-scale investment in large cooperatives and agricultural companies, and slow, fragmented innovation among small family farms. A similar land-use structure can be observed in Ukraine, albeit with a higher degree of land concentration in large agricultural enterprises. Of the approximately 39 thousand commercial agricultural enterprises, over half have a land bank of less than 100 hectares, yet they use only around 3.8% of agricultural land. In contrast, enterprises with an area of over 1,000 hectares represent a smaller numerical share, yet they control over 70% of the total land area. In particular, farms with a land bank of 1,000-5,000 hectares account for nearly half of the total area, while enterprises with over 5,000 hectares control more than a quarter (Régnier & Catallo, 2024). Thus, as in EU border countries, Ukraine's small and medium-sized entities dominate numerically, while large producers control the majority of land resources, directly affecting the scale of investment and the nature of innovation activity.

The institutional basis for developing innovative entrepreneurship in the agricultural sectors of EU border countries is the EU's Common Agricultural Policy (CAP) (Agriculture and Rural Development, n.d.), specifically its second pillar (Rural Development) (Granier & Sgueo, 2016). During the 2023-2027 programming period, Pillar II will be the main source of funding for innovation, digitalisation, and sustainable development, offsetting the limited private investment in research and development. On average, 30% of Pillar II budgets are allocated to innovative, environmentally oriented measures, while expenditure on research and development (R&D) accounts for around 1.3% of gross domestic product (GDP) (Agriculture and Rural Development, 2025).

In Ukraine, state and international support programmes aimed at modernising production, developing infrastructure and irrigation, and supporting small and medium-sized agricultural producers perform a functionally similar role to that of Pillar II. Examples include the "5-7-9%" preferential credit programme (PrivatBank, n.d.), the eRobota (n.d.) grant scheme and the Own Business... (2025) grant scheme, as well as the USAID Agricultural and Rural Development Programme (2025) and the FAO's (n.d.) programme. These instruments provide financing

for technological renewal, the development of cooperation, irrigation and processing, and partially compensate for the limited access to private investment experienced by agricultural enterprises. As in EU border countries, under such conditions, the land-use structure forms an asymmetric model of innovative entrepreneurship, with large agricultural enterprises serving as the main adopters of large-scale technological and digital solutions and small and medium-sized farms introducing innovations selectively and in a fragmented manner.

The most widespread Pillar II instruments are Measure 4 (investment in physical assets), Measure 6 (business development and young farmers), and Measure 16 (cooperation, European Innovation Partnership for Agricultural Productivity and Sustainability (EIP-AGRI)) (EU CAP Network, n.d.). In Poland and Romania, investment measures under Measure 4 account for 25-40% of European Agricultural Fund for Rural Development (n.d.) financing, which stimulates the introduction of precision agriculture technologies, digital management systems and the automation of production processes. In the Baltic States and Slovakia, Measure 16 occupies a notable share in the funding structure, reaching 15-25% of Pillar II, ensuring the creation of EIP-AGRI operational groups, the development of innovation clusters, and the testing of agri-tech solutions in pilot projects. Overall, 5-10% of national CAP strategic plans in the border countries are directly oriented towards innovation, while the fund absorption rate amounts to 70-85% (Agriculture and Rural Development, 2025). The level of innovation among agricultural enterprises in the European Union's border countries – Poland, Slovakia, Hungary, Romania and the Baltic States – remained below or close to the EU average, as confirmed by the data of the 2025 European Innovation Scoreboard (indexed to the EU average in 2018 = 100). In particular, Poland demonstrated an innovation performance index of around 80-85 points, Hungary 75-80 points, and Slovakia 70-75 points, which placed these countries in the group of moderate innovators. The lowest indicators among the analysed border countries were recorded in Romania and Bulgaria, where the innovation performance index stood at approximately 45-50 points and 55-60 points respectively, corresponding to the category of emerging innovators. These values differed markedly from those of the EU "core" countries, where the innovation performance index exceeded 130-150 points (in particular in Sweden, Denmark and the Netherlands). The Baltic States were characterised by internal differentiation in innovation development. Estonia showed an index of around 120 points, exceeding the EU average and approaching the group of strong innovators, which reflected its high level of digitalisation and the development of innovation infrastructure. At the same time, Lithuania and Latvia remained in the group of moderate innovators, with figures of approximately 95-100 points and 85-90 points respectively (Francica, 2025). In Ukraine, the level of innovation among agricultural enterprises is also characterised by moderate values, though with a more pronounced asymmetry according to farm size. The systematic use of digital and technological solutions is typical of only 15-25% of agricultural enterprises. At the same time, around 40-50% of large agricultural companies use precision agriculture tools, Internet of Things (IoT) solutions, drones and big data analytics, whereas medium-sized farms mainly implement basic digital tools (mobile applications, monitoring sensors) at a level of around 20%, and among small producers the share using innovative technologies does not exceed 10%, being concentrated primarily in biotechnological solutions and the use of new hybrids (Sukhorukova, 2024). The aggregate digitalisation index of Ukraine's agricultural sector in 2025 was estimated at around 38%, which is lower than the figures for most EU border countries; however, the expected expansion of state and donor support programmes creates the preconditions for this figure to rise to around 50% in the medium term (Ukraine Digitalisation Index, 2025). Thus, the comparison of Ukraine with the European Union's border countries shows that, in terms of overall innovation performance, the Ukrainian agricultural sector is approaching the group of moderate innovators; however, unlike the EU countries, where innovation activity is more evenly distributed across farm categories, in Ukraine innovations are concentrated primarily in large agricultural companies, while medium-sized and small

producers remain constrained in their access to capital-intensive technologies.

The economic impact of innovative entrepreneurship in agricultural enterprises in EU border regions is reflected in increased productivity, reduced costs and greater profitability. On farms that have adopted precision agriculture technologies and digital management tools, productivity growth amounts to 15-30%, while expenditure on fertilisers, plant protection products, and water is reduced by 10-25%. Consequently, the net profitability of such enterprises increases by 20-40% in large cooperatives and medium-sized farms. For small family farms, the economic impact is smaller (8-15%), due to the limited production scale and high initial costs (Choudhary *et al.*, 2025; Tomashuk *et al.*, 2025). In Ukraine, the positive economic impact of innovative entrepreneurship is constrained by the low proportion of innovation-active agricultural enterprises, which amounted to around 7–8% in 2024. Under these conditions, productivity growth of 15-30% is mainly recorded among innovative enterprises, whereas the overall contribution to gross domestic product at the level of the agricultural sector as a whole is estimated at 8-10%. The most pronounced economic effect is observed in large agricultural companies, where yield increases of 20-25% per hectare are ensured by the introduction of precision agriculture, artificial intelligence tools, and Internet of Things systems, while expenditure on fertilisers, fuel, and material resources is reduced by 15-20% (Kalina *et al.*, 2025). An additional economic effect is generated through the export channel. The introduction of innovative crops, particularly highly productive hybrids and organic products, contributed to a 10-15% increase in foreign currency earnings in 2024 (Ukraine Digitalisation Index, 2025). Thus, compared with EU border countries, Ukraine's channels for the economic effects of innovative entrepreneurship are structurally similar, but characterised by lower enterprise coverage and greater concentration of results in large agricultural holdings.

The EU's environmental requirements, particularly the provisions of the European Green Deal (n.d.), Farm to Fork strategy (n.d.) and the Nitrates Directive (Council Directive 91/676/EEC, 1991), provide an additional stimulus for innovative entrepreneurship. The requirement to reduce the use of pesticides and mineral fertilisers creates demand for precision agriculture technologies, bioenergy, and digital monitoring systems. Within the CAP, eco-schemes and Pillar II measures allocate 25-40% of resources to supporting green innovations, creating new entrepreneurial opportunities while simultaneously raising barriers to entry for traditional small farms. Innovative entrepreneurship in agricultural enterprises in the border countries of the European Union is developing in the context of fragmented land use, family farming and limited access to private investment. In such circumstances, institutional support within the framework of the EU Common Agricultural Policy is key to innovation development, particularly through Pillar II mechanisms, EIP-AGRI and EAFRD funds, which offset the structural limitations faced by small and medium-sized farms. Although there is a persistent gap in innovation performance between the EU "core" countries and the border countries, implementing digital and environmentally oriented solutions ensures productivity growth, cost reduction and higher profitability for agricultural enterprises, particularly medium-sized farms and cooperatives. Thus, innovative entrepreneurship in EU border countries plays an adaptive and stabilising role, promoting the gradual convergence of the agricultural sector with European technological and environmental standards.

DISCUSSION

The intensification of wartime risks, restricted access to resources, and tightening regulatory requirements in the agricultural sector necessitate reconsidering the role of digitalisation, innovation, and entrepreneurial practices in modernisation processes and ensuring development resilience. In both this study and the work of H. Wang *et al.* (2025), digitalisation was interpreted as a fundamental driver of agricultural modernisation, capable of improving efficiency, accelerating the innovation process and supporting sustainable development. At the same time, H. Wang *et al.* focused on the macro-regional dimension, examining the digitalisation of agricultural circulation through

integral indices and the spatial effects between regions in China. In contrast, this study considered digital and innovative entrepreneurial solutions in terms of how Ukrainian agricultural enterprises adapted to wartime risks and resource constraints. This shifted the focus from regional dynamics to internal production and managerial transformations. A similar logic can be seen in the approach of Y. Wei & C. Sutunyarak (2025), albeit with a different emphasis. Both studies recognised innovation and digital tools as key factors in improving the performance of agricultural enterprises and overcoming structural constraints. However, Y. Wei & C. Sutunyarak primarily interpreted innovative development through the lens of a digitally inclusive financial system, considering financial constraints to be the central intermediary mechanism influencing the innovative activity of Chinese agricultural companies. In this study, however, innovative entrepreneurship was interpreted much more broadly as a comprehensive strategy for modernising production and management processes in wartime. Taking a broader comparative approach, it was found that the study by X. Meng *et al.* (2024) shared the view that innovation and digital technologies are key drivers of change in the agricultural sector. X. Meng *et al.*, however, focused on the educational and institutional dimension of change, analysing the training of new professional farmers and the development of digital competencies. In contrast, this study considered human capital not as an independent object of analysis, but as part of a broader entrepreneurial logic aimed at renewing production models and enhancing the productivity and resilience of Ukrainian agricultural enterprises.

While there was a similarity in theoretical positions, there was a difference in analytical scale compared to the work of X. Xu & K. Zhang (2025). In both studies, innovation and entrepreneurial activity were considered essential for transitioning the agricultural sector to new, higher-quality development models. However, X. Xu & K. Zhang worked at the macro level, assessing the influence of rural entrepreneurship on the formation of "new qualitative productive forces" in China through technological innovation, industry integration, and spatial effects. In the present study, however, the focus was on micro- and meso-level processes where innovative entrepreneurship acted as an instrument for renewing the production and management practices of specific agricultural enterprises amid wartime risks. Further comparison with Y. Pan *et al.* (2024) revealed a shared interpretation of innovative entrepreneurship as a factor in agricultural modernisation. At the same time, Y. Pan *et al.* concentrated on a macro-regional analysis of China, paying attention to the spatial spill over effects of farmers' entrepreneurship and its influence on rural development. In contrast, the present study considered innovative entrepreneurship through the lens of the internal transformation of Ukrainian agricultural enterprises, emphasising the strengthening of financial resilience and the adaptation of business models to wartime challenges.

A comparison with the work of M. Gao *et al.* (2025) revealed a mutual recognition of innovation as a pivotal element in the sustained modernisation of the agricultural sector. Meanwhile, M. Gao *et al.* focused on green and digital macro-level transformations, examining them through the lens of environmental efficiency, structural shifts, and the political and institutional mechanisms of sustainable development. Against this background, the present study stands out for its practical focus: it interprets innovative entrepreneurship as a mechanism for renewing the production and management processes of Ukrainian agricultural enterprises with the aim of enhancing productivity and financial resilience in wartime and in the face of resource constraints. A comparison with the study by J. Wang & L. Zhang (2024) revealed a shared vision of the role of digital technologies in agricultural modernisation, while also highlighting different analytical perspectives. J. Wang & L. Zhang primarily considered digital transformation through the lens of the regulatory environment and environmental requirements, analysing the effect of combining digitalisation and environmental regulation on the quality of innovation development in the sector. In contrast, the present study shifted the focus from sectoral and regulatory effects to individual agricultural enterprises in Ukraine. Here, innovative entrepreneurship was interpreted as a practical instrument for renewing managerial

and production processes, as well as strengthening financial resilience amid wartime risks.

The transition from territorial to financial and institutional aspects of innovation was clearly evident when compared with A. Mavluda's work (2025). While both studies recognised the importance of investment and modernisation as prerequisites for improving enterprise performance, the logic of analysis differed substantially. A. Mavluda focused on the macro- and meso-economic mechanisms that support the real sector, particularly the role of financial markets, bank lending, and investment indicators. In the present study, however, financial resources were considered a consequence of entrepreneurial decisions, and digital technologies were viewed as a means of directly influencing the productivity and financial resilience of Ukrainian agricultural enterprises operating in wartime and under resource constraints. In comparison with the approach of N. Chaparro-Banegas *et al.* (2024), the environmental dimension of innovative transformation became central. While both studies recognised innovation as a key factor in strengthening the resilience of the agricultural sector, N. Chaparro-Banegas *et al.* focused on eco-innovation in the Spanish agri-food sector, emphasising environmental sustainability and compliance with EU policies. In contrast, the environmental component in the present study was not considered an independent objective, but was integrated into the broader logic of innovative entrepreneurship, which aimed to modernise production and management processes, and ensure financial resilience in the face of heightened risks.

Another dimension of innovative transformation emerged when the study by J.M. García-Gallego *et al.* (2025) was considered. Both approaches recognised the role of digital solutions and new business models in overcoming the structural limitations of agricultural development. However, J.M. García-Gallego *et al.* focused specifically on e-marketplace platforms as a means of integrating small-scale producers into value chains. They analysed the barriers to implementation and commercial acceptability of such models in Spain. By contrast, the present study considered innovative entrepreneurship much more broadly as a comprehensive strategy for the technological and managerial renewal of Ukrainian agricultural enterprises, extending beyond platform solutions to encompass the entire business management system. The final perspective in the comparative analysis was shaped by a comparison with the work of J.M. Ortiz-Villajos (2024), which differed fundamentally in terms of its time horizon and methodology. While both studies recognised innovation as a fundamental factor in economic development, J.M. Ortiz-Villajos analysed innovation activity within long-term historical dynamics, tracing the wave-like nature of innovation among Spain's business elites from 1870 to 1970. By contrast, the present study considered innovation in a contemporary crisis context, where digital and technological solutions served an applied function by ensuring the adaptation of Ukrainian agricultural enterprises to wartime risks and preserving their financial resilience.

The comparative analysis revealed variations in the interpretation of the mechanisms through which digitalisation and innovation influence the development of the agricultural sector, influenced by the selection of analytical level and research focus. In a number of studies, macro-, regional, financial or environmental approaches predominated, whereas internal entrepreneurial processes were considered only indirectly. This study emphasised the innovative entrepreneurship of agricultural enterprises as a mechanism for renewing production and management processes, and for adapting to wartime risks and resource constraints. This outlined the micro- and meso-level dimensions of innovative transformations.

CONCLUSIONS

The present study demonstrated that, between 2020 and 2025, innovative entrepreneurship became one of the key factors in the modernisation of Ukrainian agricultural enterprises amid wartime risks, macroeconomic instability, and restricted access to financial resources. During this period, the proportion of agricultural enterprises actively engaged in innovation increased from 6.2-6.5% in 2020 to 7-8% in 2024-2025. This reflects the gradual strengthening of the role of digital and technological solutions in agricultural

production, despite the general decline in investment activity in 2022. At the same time, innovations were predominantly adaptive in nature, aimed at reducing costs, compensating for labour shortages, and improving the controllability of production processes. The technological modernisation of Ukrainian agricultural enterprises was characterised by asymmetry in terms of the scale and depth of implementation. Around 70% of farms used fuel level trackers and machinery condition monitoring systems, around 60% used linear navigation systems and field dynamics analysis systems, and only around 12% used artificial intelligence algorithms. Capital-intensive precision agriculture tools remained concentrated among large agricultural companies; the proportion of enterprises that systematically used drones was estimated at 10-12%, while the proportion that used RTK navigation was around 52%. Between 2021 and 2023, approximately 3.1 million hectares were treated using drones, compared to up to 1 million hectares annually between 2024 and 2025, indicating the concentration of innovation among entities with greater investment capacity.

The economic results of implementing innovations confirmed their positive impact on productivity and financial performance. Using agrochemical soil analysis, field zoning and differentiated resource application ensured yield increases ranging from 4% to 22%, depending on the crop. The MHP case study showed that, after the operating margin fell to 2% and the EBITDA margin to 8% in 2022, the company had restored these figures to 11-12% and 16-17%, respectively, by 2023-2024, while maintaining a positive net financial result in 2025. This confirms the stabilising role of innovative entrepreneurship. A comparative analysis of countries bordering the European Union showed that innovative approaches to modernising agricultural enterprises are implemented under fundamentally different institutional conditions. In Poland, Hungary, Slovakia and Romania, the EU Common Agricultural Policy plays a key role, with around 30% of Pillar II funds directed towards innovation and environmentally oriented measures. In these countries, the share of innovation funding within Pillar II amounts to an average of 5-10% of national strategic plans, while the fund absorption rate reaches 70-85%. Consequently, farms that have adopted digital and precision technologies have achieved a 15-30% increase in productivity and a 20-40% rise in net profitability, which substantially surpasses the average performance of Ukrainian enterprises. One limitation of the study is its use of aggregated data and cases of large agricultural enterprises, which restricts the applicability of the results to small and medium-sized farms. Further research should focus on micro-level econometric analysis, taking into account institutional and regional constraints.

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Роль інноваційного підприємництва в модернізації аграрних підприємств України

Анотація. Метою даного дослідження було обґрунтування ролі інноваційного підприємництва у підвищенні результативності та фінансової стійкості аграрних підприємств України в умовах воєнних і макроекономічних викликів. Методологія дослідження ґрунтувалася на емпіричному підході із застосуванням структурно-логічного, порівняльно-динамічного, статистично-динамічного, інтервального, описового, трендового, технологічно-функціонального, та інституційно-порівняльного аналізу, узагальнюючого аналізу джерел та кейс-стаді діяльності аграрного підприємства. Результати дослідження показали зростання частки інноваційно активних аграрних підприємств з 6,2-6,5 % у 2020 році до 7-8 % у 2024-2025 роках, попри скорочення загальних капітальних інвестицій у 2022 році. Встановлено, що трекери рівня пального та системи моніторингу технічного стану машин застосовувалися приблизно у 70 % господарств, тоді як системи лінійної навігації та аналізу динаміки поля – у близько 60 %. У 2021-2023 роках із використанням дронів було оброблено близько 3,1 млн гектарів, а у 2024-2025 роках – до 1 млн гектарів щорічно. Диференційоване внесення ресурсів забезпечувало приріст урожайності на 4-22 %. Аналіз діяльності «Миронівського хлібопродукту» засвідчив відновлення операційної маржі до 11-12 % та зростання прибутку до сплати відсотків, податків, амортизації та зносу до 16-17 % у 2023-2024 роках. Порівняння з Польщею, Словаччиною, Угорщиною та Румунією показало, що у цих країнах на інноваційні напрями спрямовується 5-10 % коштів другого стовпа Спільної аграрної політики Європейського Союзу при рівні освоєння 70-85 %, що забезпечує приріст продуктивності на 15-30 % і рентабельності на 20-40 %. Практичне значення дослідження полягає у можливості використання його результатів аграрними підприємствами для обґрунтування рішень щодо впровадження інновацій

Ключові слова: технологічне оновлення; агробізнес; інноваційна активність; інвестиції; трансформації; стійкість