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Food security strategies in the context of environmental and economic fluctuations in Ukraine

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► **Abstract.** The study aimed to assess the impact of investments in agricultural technology on the productivity, economic efficiency and profitability of farming enterprises. The emphasis was on analysing yields of the three leading agricultural holdings in Ukraine: Svarog West Group, Stepova and Agroproduct LLC, which operate in different natural and climatic conditions. The methodology involved collecting data for three agricultural seasons (2021-2023), which was used to identify long-term trends and determine the impact of technology investments on key performance indicators of enterprises. A correlation analysis with the calculation of Pearson's coefficients was used to assess the relationship between agricultural technology expenditures and yields. The economic efficiency was calculated based on profitability and resource efficiency, which compared the results between agricultural holdings and identified management features in different conditions. The main results showed that investments in agricultural technology have a positive impact on yields, although their effectiveness depends on the specialisation of the farms and environmental conditions. For Svarog West Group, a strong correlation between investment and yield was determined ($r = 0.85$), which highlights the importance of technological innovation. Agroproduct LLC demonstrated the highest level of profitability (40%), which indicates effective cost management. In turn, Stepova

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achieved the highest efficiency of resource use (0.0056 t/thousand UAH) due to its specialisation in seed production. The results showed that it is necessary to combine technological innovation with adaptation to climate conditions to ensure the long-term efficiency of agricultural production. These findings can be useful for researchers, managers and practitioners involved in agricultural sector development and seeking ways to achieve food security in a changing climate

► **Keywords:** agronomic technologies; profitability; yield; climate change; food security; correlation analysis; agricultural management

► Introduction

Agribusiness is a key sector of the Ukrainian economy, ensuring not only domestic food security but also a significant contribution to the global agricultural market. Modern agriculture is at the crossroads of several important challenges, such as rising demand for food, climate change and the need for sustainable resource use. According to a study by S. Kvasha *et al.* (2024), the global population is growing, which requires innovative approaches to increase agricultural productivity and ensure food security. At the same time, many scholars emphasise the need to balance economic efficiency with environmental sustainability (Kushniruk *et al.*, 2021; Kotykova *et al.*, 2022). In this context, the role of large agricultural holdings should be studied and their efficiency assessed in both economic and environmental terms. Various studies already highlighted the impact of agricultural technologies on farm yields and economic efficiency. For instance, M. Haydaroğlu and P. Bilgiç (2024) demonstrated that innovations in seed and soil management increase crop productivity by 15-20%. However, L. Yang (2024) noted that investments in technology may be less effective without accounting for climate change. This challenge is particularly relevant for Ukraine, where natural and climatic conditions vary between regions, creating additional risks for agricultural production (Vernooy, 2022).

Despite substantial research, not all aspects of the efficiency of large agricultural holdings were sufficiently covered. Most previous studies focus on either technical productivity or economic performance. To a lesser extent, how different business models respond to external challenges, such as economic crises and climate change, has been studied (Henderson, 2022). In addition, agriculture holdings in the context of sustainable development often lack complexity. The challenge of this study is to determine how investments in agricultural technology and efficient resource management affect the economic stability and productivity of large agricultural holdings. In addition, it is necessary to determine which management models are most effective in the face of economic instability and environmental challenges. The use of modern technologies not only increases yields but also contributes to economic profitability, if they are adapted to local climatic conditions (Bulgakov *et al.*, 2019). The study of this topic will help identify the best approaches to agricultural business management and develop recommendations for increasing the productivity and sustainability of agricultural enterprises.

In this regard, a study of Ukrainian agricultural holdings, which have different specialisations and operate in different regional climates, is particularly important for determining what strategies can ensure long-term food security. Thus, the research relevance is determined by several factors. The first is the growing role of agriculture holdings in the structure of Ukrainian agriculture. In recent years, large agricultural enterprises have become key players in the market, controlling a significant portion of grain and oilseed production (European Commission, 2023). Second, global climate change is creating new risks for the agricultural sector, forcing producers to adapt their technologies and management practices (Ploeg, 2020). Thirdly, despite considerable scientific interest in agricultural technologies, the question of how different management models affect the economic and environmental outcomes of farming remains open (Ohlan & Ohlan, 2022). In this context, it is also necessary to address the current economic and political conditions affecting agribusiness in Ukraine, including rising energy and fertiliser costs, the impact of climate change on agriculture, and the need to adapt to new market conditions. Assessment of profitability, resource efficiency and the impact of agricultural technologies on yields will help to develop practical recommendations for optimising the management of large agricultural enterprises in the face of economic and climate challenges.

The study aimed to analyse the relationship between investments in agricultural technologies and their impact on yields, profitability and resource efficiency of agricultural holdings to identify optimal strategies for managing agricultural enterprises in the context of climate change.

►Materials and methods

The selection included 3 leading agricultural holdings from different regions of Ukraine, which differ in terms of natural and climatic conditions. During three agricultural seasons (2021-2023), data on the production performance and financial activities of the three leading agricultural holdings in Ukraine were collected: Svarog West Group, Stepova, and Agroproduct LLC. These companies are in different regions of the country and operate in different natural and climatic conditions, which was used to compare their efficiency and adaptation to environmental and economic changes. The assessment of efficiency and relationships between indicators is carried out using several economic and statistical approaches, including correlation analysis and calculation of key performance indicators.

Svarog West Group specialises in various areas of activity: growing grain, oilseeds and industrial crops, dairy and meat products, growing fruits and berries, own plant for seed production and processing, and storage of products. This agricultural holding is highly diversified, which makes it more resilient to market and climate fluctuations.

Stepova the core business is the development of new corn hybrids and seed production. Narrow specialisation provides a competitive advantage in creating productive varieties but increases dependence on demand for seeds.

Agroproduct LLC: the production of crop and livestock products. The combination of both areas creates a synergy: crop residues are used for animal feed, and organic fertilisers from livestock are returned to the soil.

The following indicators were used to assess the impact of climate change on the operations of agricultural holdings: average annual temperature, precipitation and frequency of extreme weather events in the regions where they are located. This data served as the basis for analysing the impact of climatic conditions on costs, yields and overall economic performance of enterprises. The sources of climate data were state meteorological services that provided data on weather conditions for the study period (2021-2023), as well as satellite observations to verify and refine the indicators. This approach determined not only average annual changes but also specific climate events that could affect the operations of agricultural holdings. The analysis was based on the integration of climate data with the production and financial performance of agricultural holdings. This approach was used to track dependencies and develop recommendations for improving climate change resilience. Pearson's correlation coefficient is effective in assessing the relationship between investment and productivity, as it measures the strength and direction of a linear relationship between two quantitative variables. The correlation coefficient is calculated using the formula (1):

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(Y_i-\bar{Y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})\sum_{i=1}^{n}(Y_i-\bar{Y})}}, \quad (1)$$

where x_i and Y_i – variable values (e.g. yield level and agricultural inputs) for i-th observation; $\bar{x}$ and $\bar{Y}$ – average values of variables X and Y; n – number of observations. Correlation analysis was used to assess, for example, the relationship between yields and investments in agricultural technology, or between changes in climate conditions and farm productivity. It also determined how economic changes, such as rising input prices, affect the operations of agricultural holdings.

Profitability reflects how profitable a farm is by showing how much profit is generated for each hryvnia of costs. This metric is widely used to assess the efficiency of both agricultural holdings and farms (2):

$$R = \frac{P-C}{C} \times 100\%, \quad (2)$$

where R – profitability; P – profit; C – expenses.

The resource efficiency ratio (E) shows how many units of output (e.g. tonnes of grain) are produced per unit of input. The higher the E, the more efficiently the farm uses its resources. It is useful for comparing agricultural holdings and farms with similar inputs (3):

$$E = \frac{\text{Yields}}{\text{Total costs}}, \quad (3)$$

where E – resource efficiency factor; yields is the volume of output (e.g. tonnes of grain per hectare); Total costs is the total cost of production (fertiliser, fuel, water, wages, etc.).

A higher ratio indicates a rational use of resources and increased productivity. This compares the performance of different businesses at similar costs and identifies which ones are better able to adapt to changes in the market or climate.

▸ Results

Specific investments in agricultural technologies for each agricultural holding were considered, the amounts of these investments, and their impact on yields were determined, and the return on investment based on productivity gains was calculated. The impact of investments in agricultural technologies was reflected in this study based on data for the period 2021-2023. Improving the productivity of agricultural holdings such as Svarog West Group, Stepova and Agroproduct LLC is crucial in ensuring Ukrainian food security. Increased yields result in higher agricultural output, which reduces dependence on imports and ensures stable supply on the domestic market. This situation helps to reduce price fluctuations and increase the availability of food for the population, which is essential for maintaining economic and social stability in the face of crises or climate change.

In the context of Svarog West Group, investments in precision farming systems, including the use of GPS navigation and drones for mapping and field analysis, are proving to be effective, as they significantly improve resource management and yields. This optimised field processing and reduced fertiliser use by 15%, which improved the economic results due to lower costs. The introduction of a system that achieves real-time moisture levels has mitigated unnecessary irrigation, reducing water consumption by 20%. This ensured a stable yield level even in conditions of moisture deficit. The introduction of new biological products to replace some chemical pesticides has reduced the risk of crop loss due to pest resistance and improved yields. The use of GPS navigation and drones reduced the amount of fertiliser and optimise field cultivation, which increased yields by 8% and reduced production costs by 10%. This had a positive impact on profitability, which was reflected in economic indicators (State Statistics Service of Ukraine, 2024).

Spending on splicing ensured optimum moisture level, which further increased yields by 5%, and during dry seasons, which reduced costs by 15%. The use of biological products to protect crops reduced pest losses, increasing yields by 6% and improving profitability, resulting in a 7% reduction in the profitability margin. Investments in agricultural technologies during the study period (2021-2023) totalled approximately (UAH 1,200 thousand). The main expenditures were made on precision farming systems, automated management of agricultural operations and the use of biological products for plant protection. Innovations (precision farming systems and biological products) increased yields by 20%, which resulted in an additional income of (UAH 1,500 thousand) (State Statistics Service of Ukraine, 2024).

In the context of Stepova, investing in the treatment of corn with highly effective products to improve the quality of genetic material, increased yields by 10%. The use of a precision irrigation system equipped with sensors, reduced water and energy consumption by 15%, increasing resource efficiency. Installation of a greenhouse where temperature and humidity can be controlled to reduce the impact of external climatic factors. This extended the growing season and maintained yields even in unstable weather conditions. Specialisation in treatments helped to increase its disease resistance, which increased

yields by 10%. Growing high-quality seed had a positive impact on profitability, which increased by 8% (State Statistics Service of Ukraine, 2024). Saving water and energy through automation has led to a 5% increase in profitability due to lower operating costs and a 7% increase in yield. By stabilising growing conditions, high yields were maintained even in adverse weather conditions. This increased the company's revenues by 12%, especially in a changing climate, while maintaining a stable level of profitability. Investments were approximately (UAH 800 thousand), of which a significant part was spent on the use of innovative treatment technologies, automation of splicing and climate control in greenhouses. This allowed the company to reduce its dependence on climatic factors and improve the quality of its products. Processing technologies and climate control increased yields by 15%, which brought in (UAH 1,100 thousand) in additional income (State Statistics Service of Ukraine, 2024).

In turn, in the context of Agroproduct LLC, investments in equipment for analysing macro- and microelements justification ensured optimal fertiliser rates, which increased yields by 12% and reduced fertiliser costs. Agricultural operations management systems. Implementation of an agricultural operations management system that allows for real-time monitoring of material costs and assessment of the efficiency of each stage of production. This helped optimise production costs and increase profitability. The use of biological pest control products reduced the cost of chemical pesticides by 18% and increased the risk of environmental pollution. Optimisation of fertiliser application through analysis increased yields by 12%, which led to increased economic efficiency by reducing fertiliser costs by 10%. Agricultural operations management systems. These systems helped control costs and increased productivity by 9%. It also led to a 6% increase in profitability, which reduced unproductive costs. The use of biosecurity has reduced chemical pesticide costs by 18%, which has increased the overall profitability of the company by 4% and reduced environmental costs. The total investment amounted to approximately (UAH 1,000 thousand). The main costs were invested in a feasibility study to optimise fertiliser, the farm management system and the use of biosecurity. These investments have contributed to increased yields and resource efficiency. The feasibility analysis and the farm management system increased yields by 18%, resulting in an additional income of (UAH 1,400 thousand) (State Statistics Service of Ukraine, 2024).

Environmental sustainability is an important component of food security, especially in the face of climate change (Zibtsev *et al.*, 2024). Reducing the use of chemical plant protection products and optimising resource consumption helps preserve ecosystems and improve soil fertility. This has a positive impact on the long-term productivity of agricultural companies such as Svarog West Group, Stepova and Agroproduct LLC. Rational use of resources and implementation of environmentally friendly practices also reduce the negative impact on the environment, which ensures the sustainability of agricultural systems and contributes to the stability of food production. Thus, an environmentally friendly approach to agriculture supports food security and ensures sustainable development in the long term. These three agricultural holdings represent different business models: Svarog West Group with diversified activities, Stepova with specialisation, and Agroproduct LLC as an integrated crop and livestock production system. Table 1 summarises the costs, revenues and profits for the three agricultural holdings over the study period (2021-2023). Average yields are also included for comparison.

Table 1. Average expenses and income for 2021-2023 (thousand UAH)

Agricultural holding	Total costs	Income	Profit	Yield (t/ha)
Svarog West Group	1.200	1.500	300	5.2
Stepova	800	1.100	300	4.5
Agroproduct LLC	1.000	1.400	400	5

Source: compiled by the authors based on State Statistics Service of Ukraine (2024)

Svarog West Group has the highest costs (UAH 1,200 thousand) but also achieves high revenues (UAH 1,500 thousand) and profit (UAH 300 thousand). Yields of 5.2 t/ha indicate the effective use of agricultural technologies. This is due to the diversification of activities and the use of innovations in crop and livestock production. Stepova incurred the lowest costs (UAH 800 thousand) and relatively low revenues (UAH 1,100 thousand). Despite the smaller scale of its operations, profits remain stable (UAH 300 thousand). Yields of 4.5 t/ha indicate specialisation in seed production and cost efficiency. Agroproduct LLC has balanced expenses (UAH 1,000 thousand) and income (UAH 1,400 thousand), with a profit of UAH 400 thousand. Yields of 5.0 t/ha demonstrate the synergy between crop and livestock production, which allows for efficient use of resources. The analysis demonstrated a positive correlation between investment in agricultural technology and yields. This confirms that modern technologies are critical in increasing productivity. The impact of investments in agricultural technology on yields depends on a range of factors that can vary significantly between farms. This impact varies depending on the natural and climatic conditions, business strategy and production specialisation of each farm, with business model and specialisation affecting the final results. Pearson's correlation coefficient (r) measures the strength and direction of a linear relationship between two variables – in this case, between agricultural technology expenditures and yields. The coefficient ranges from -1 to 1, where: r = 1: perfect direct correlation (the two variables increase together), r = -1: perfect inverse correlation (one variable increases and the other decreases), r = 0: no linear relationship between the variables. Table 2 presents the results of the correlation analysis (Table 2).

Table 2. Results of correlation analysis for each agricultural holding

Agricultural holding	Pearson's coefficient (p)	Correlation power
Svarog West Group	0.85	Strong direct correlation
Stepova	0.72	Moderate direct correlation
Agroproduct LLC	0.78	Strong direct correlation

Source: compiled by the authors

The correlation coefficients show that agricultural technology plays an important role in increasing yields, but the extent of its impact differs between farms due to different production approaches and conditions.

Svarog West Group: R = 0.85, a high coefficient, which indicates a strong direct correlation between spending on agricultural technology and yields. Therefore, investments in modern technologies, such as automation and innovative crop protection products, significantly improve results. As the agricultural holding is involved not only in crop production but also in livestock and seed production, technological innovations increase the efficiency of all areas of production.

Stepova. R = 0.72 indicates a moderate direct correlation. Although technology is also of substantial effect, its impact is not as significant as in Svarog West Group. The company's specialisation in corn seed production and breeding partly explains this result, as its main investments are directed at developing new hybrids rather than increasing the yield of the final product.

Agroproduct LLC: R = 0.78, a positive correlation between expenditure on agricultural technology and yield. The integration of crop and livestock production allows the company to use technology to increase yields and optimise resources. For instance, crop residues are used as feed and organic waste is used as fertiliser, which also affects productivity.

The strong correlation between investment and yields for Svarog West Group and Agroproduct LLC confirms that innovative agricultural technologies are a key factor in the success of these businesses. Svarog West Group can continue to invest in technologies aimed at automating and managing large amounts of data to improve efficiency across the board. Agroproduct LDT can expand its use of agricultural technology to improve integration between crop and livestock production, resulting in even greater productivity and efficiency. Stepova shows a moderate correlation, which confirms the impact of specialisation in seed production on production efficiency. Expenditures on agricultural technology are more focused on breeding than on directly increasing the yield of the final product. Stepova should introduce new technologies to optimise production and increase profitability. The variability of the results shows that, while technology has a significant impact on productivity, natural and climatic conditions and management practices also play an important role. This underscores the importance of adapting business models to specific operating conditions. This correlation analysis confirms that technological investment is a major factor in increasing farm yields and efficiency, but that farm-specific and regional conditions need to be taken into account. Table 3 shows the calculations of profitability for each of the three enterprises based on their costs and profits.

Table 3. Profitability calculations

Agricultural holding	Profit (P)	Expenses (C)	Profitability (R, %)
Svarog West Group	300	1,200	25
Stepova	300	800	37.5
Agroproduct LLC	400	1,000	40

Source: compiled by the authors based on State Statistics Service of Ukraine (2024)

Agroproduct LLC demonstrated the highest profitability (40%), which indicates efficient use of resources and well-balanced costs. The company combines crop and livestock production, which optimises the use of production waste and reduces overall costs. Despite the high level of technological investment, the company achieves excellent financial performance. Stepova has a profitability of 37.5%, which is also a high level. Specialisation in corn breeding and seed production allows the company to maintain low production costs by focusing on optimising its cost processes. The high profitability is due to cost-effective resource management, although agricultural-technological investments are not as large as those of other agricultural holdings. Svarog West Group has a profitability of 25%. This is lower than other companies due to its more diversified operations: the company is engaged not only in crop production but also in livestock, horticulture and seed production. This diversity requires significant investments in different areas, which affects the overall costs and reduces profitability. The profitability analysis shows that Agroproduct LLC has the highest resource efficiency (40%). This confirms the importance of integrating different areas of production and using agricultural technologies to increase productivity. Stepova also demonstrates high profitability due to its narrow specialisation and low production costs.

The lower profitability of Svarog West Group (25%) suggests that diversified businesses may have lower short-term financial performance. However, this model ensures sustainability and risk reduction in the long term. Agroproduct LLC should continue to develop integrated production processes and optimise costs to maintain high profitability. Stepova should invest in new breeding technologies and expand the market for its seeds, which could increase profitability. Svarog West Group should address the efficiency gains in certain areas (e.g., livestock

automation) and use cost analysis to identify the most profitable production processes. This analysis highlights the importance of prudent resource management and diversification to achieve sustainable development and economic efficiency in the agricultural sector. Resource efficiency determines how efficiently a company uses its inputs. It measures how many units of output (in this case, tonnes of grain per hectare) are produced for every thousand hryvnias of total costs. Table 4 shows the results for each of the three agricultural holdings.

Table 4. Resource efficiency ratio

Agricultural holding	Yield (t/ha)	Total expenses (thousand UAH)	E (tonnes/thousand UAH)
Svarog West Group	5.2	1.200	0.0043
Stepova	4.5	800	0.0056
Agroproduct LLC	5	1.000	0.005

Source: compiled by the authors based on State Statistics Service of Ukraine (2024)

Stepova demonstrated the highest efficiency ratio of 0.0056 t/thousand UAH. This means that the company receives 5.6 kg of grain for every thousand hryvnias of costs. Such a high figure is explained by the specialisation in breeding and seed production, which allows the company to optimise production costs and produce quality products with less investment. Agroproduct LLC has an efficiency ratio of 0.005 tonnes/thousand UAH. This indicates an efficient use of resources, although slightly lower compared to Stepova. The high productivity of this company is ensured by a combination of crop and livestock production, which allows for optimal use of secondary resources (e.g. organic fertilisers). Svarog West Group demonstrated the lowest efficiency ratio of 0.0043 t/thousand UAH. Despite higher yields (5.2 t/ha), the high costs of supporting the various activities (livestock, horticulture, seed production) resulted in lower resource efficiency. This underlines that diversified enterprises may have higher costs due to a wider range of operations. The analysis of the resource efficiency ratio shows that specialised enterprises, such as Stepova, achieve the highest efficiency rates due to their narrow specialisation and cost optimisation. Enterprises engaged in diversified operations (e.g. Svarog West Group) may have a lower ratio due to the higher costs of maintaining different production lines. This analysis confirms that effective resource management is critical to improving productivity and economic efficiency, especially in times of economic change.

The results of the study showed that investments in agricultural technologies and rational resource management have a significant impact on productivity and economic efficiency, as well as the yield of agricultural enterprises. The positive correlation between agricultural technology expenditures and yields demonstrates the importance of innovation in increasing productivity. This is particularly evident for Svarog West Group, where the correlation coefficient of R = 0.85 indicates a strong link between investment and yield growth. Innovations in seed production, the use of modern machinery and the optimisation of agricultural practices have allowed this company to achieve high yields (5.2 t/ha). However, the diversified nature of the business increases costs, which reduces overall economic efficiency. Agroproduct LLC has the highest profitability. This enterprise achieved a profitability of 40%, indicating a high level of cost management and profitability. The combination of crop and livestock production allows for efficient use of resources: organic fertilisers from livestock production reduce chemical costs, improving soil quality and yields (5 t/ha). The company's profitability demonstrates the optimal use of resources, even in difficult economic conditions. Stepova demonstrates the highest resource efficiency ratio. The efficiency ratio of 0.0056 t/thousand UAH indicates that Stepova uses its investments most rationally. This is attributable to the narrow specialisation in breeding and seed production, which requires lower costs but ensures high-quality products. This approach reduces financial risks and optimises production. This study confirms that the efficiency of agricultural production depends on both the level of technological investment and the ability of enterprises to adapt to changing conditions. High profitability and resource efficiency indicate that enterprises that skilfully combine innovation with good management can achieve significant results. However, to ensure long-term sustainability and food security, strategies need to be developed that consider both economic and environmental factors.

Achieving food security requires a comprehensive strategy that addresses environmental and economic challenges, climate change, and the structural characteristics of the agricultural sector. The main strategic components are state support (direct subsidies, preferential lending to farmers), infrastructure development (logistics, storage facilities, digitalisation of agribusiness), stimulating investment in the latest agricultural technologies, and legislative initiatives to harmonise the regulatory environment. Based on the experience of other countries, such as the Netherlands or Israel, the integration of precision agriculture, irrigation systems and climate change adaptation programmes remains a priority. The experience of other countries in precision agriculture and water management demonstrates significant potential for improving food security. For instance, Israel uses sensor technologies and intelligent water management systems that have reduced water consumption by 50% and increased yields by 25% through optimised irrigation. The Netherlands has successfully applied precision agriculture using the Internet of Things, machine learning, and cloud computing, which has increased yields by 15-20%, reduced losses due to crop diseases and stress, and improved soil fertility management (Ramdinthara & Bala, 2019; Lopushynska *et al.*, 2022).

For Ukraine, the implementation of these approaches through government support programmes is crucial. This includes subsidies for sensor-based soil monitoring systems, the development of research clusters to adapt technologies to local conditions, and the establishment of cooperation with international partners. The development of

training programmes for farmers on the use of new technologies and risk management is also needed. Given the success of other countries, such initiatives could increase yields and reduce dependence on weather conditions in Ukraine. It is necessary to create financial support mechanisms through government guarantees and partnerships with international organisations to attract investment in agriculture. Adaptation to climate change involves developing risk management programmes, such as crop insurance, drought-resistant crops, and water optimisation (Ivanova *et al.*, 2021). Improving logistics can include developing rail transport, modernising ports and ensuring efficient distribution of resources within the country.

The state is central in ensuring food security through financial support, regulatory measures and partnerships with international organisations. One of the most effective mechanisms is the introduction of targeted subsidy programmes for the purchase of modern machinery, sensor systems and software for precision farming (Bulgakov *et al.*, 2017). For instance, similar programmes in Germany provide up to 40% of the cost of innovative agricultural technologies, which has significantly increased yields and reduced environmental impact. In Ukraine, similar subsidies could be targeted at farmers who introduce soil monitoring tools, crop monitoring drones or automated irrigation systems. Financing for small and medium-sized farmers can be provided through concessional lending programmes. For instance, Poland has a programme where farmers receive low-interest loans subsidised by the state. In Ukraine, a similar model could stimulate the development of small farms, which make up a significant part of the agricultural sector (Javed *et al.*, 2022; Berxolli *et al.*, 2023).

Crop insurance is another vital mechanism. The US has a Federal Crop Insurance programme where the government covers up to 60% of the insurance premium. In Ukraine, this is possible through partial compensation of the cost of insurance for farmers who grow strategically important crops such as wheat or corn. Partnerships with international organisations, such as the Food and Agriculture Organisation, the World Bank and the European Union, can provide access to long-term financing grants. For instance, the Food and Agriculture Organisation supports sustainable water use programmes in Southern Africa, while the World Bank finances agricultural innovation through low-interest loans to developing countries (Ncube *et al.*, 2018). In Ukraine, it is advisable to create a trust fund for the development of the agricultural sector, attracting investments from these organisations for the construction of infrastructure, training of farmers and digitalisation of agribusiness. Practical measures for Ukraine should address the specifics of the regions. For instance, in the southern regions, the creation of water supply systems, and in the western regions, the strengthening of organic farming. A programme to train farmers in new technologies and move towards more sustainable production practices is also needed. Overall, a clear strategy that integrates international experience and national priorities is key to achieving food security.

▸ Discussion

The results of this study show that investments in agricultural technology have a positive impact on yields, but the level of this impact varies between agricultural holdings due to the specifics of their operations and climatic conditions. The highest correlation between agricultural technology expenditures and yields was found for Svarog West Group ($r = 0.85$), which correlates with the study by H. Ayeb &R. Bush (2019), who emphasised that innovative technologies in agriculture can increase productivity by 15-20%. This indicates a significant impact of technological innovation on productivity and is consistent with the findings of B. Boulay *et al.* (2020), who emphasised that the effectiveness of technologies varies depending on environmental conditions and needs to be adapted. This emphasises the importance of a flexible approach to technology adoption at enterprises operating in different climatic zones.

The analysis of Stepova Agroholding showed a moderate correlation between agricultural technology expenditures and yields ($r = 0.72$). This can be attributed to the specialisation in seed production, where the focus is not on increasing yields but on improving genetic material. Similar conclusions were reached by S. Madsen *et al.* (2020), determining that seed farms have a different productivity focus that affects economic performance. The analysis of the resource efficiency coefficient showed that the highest indicator was for Stepova Agroholding (0.0056 t/thousand UAH). For Agroproduct LLC, the correlation between investment and yield was also high ($r = 0.78$), indicating the efficient use of technology to increase productivity. This is consistent with the study by B. Feyisa *et al.* (2024), emphasising that optimal resource management allows for high yields even in conditions of limited access to resources.

The profitability analysis also revealed interesting patterns. The highest profitability was shown by Agroproduct LLC (40%), which indicates effective cost management. This result corresponds to the findings of W. G. Moseley (2013), noting that effective cost management is a key factor in the success of agricultural enterprises, regardless of the level of investment in technology. This may be due to efficient cost management and optimisation of production processes. Other studies, such as M. Babych & A. Kovalenko (2018), who analysed the efficiency of large agricultural holdings, also demonstrated that higher profitability can be achieved through efficient resource management even with high technology costs. O. Kotyková & M. Babych (2021) noted that high levels of investment in agricultural technology do not always lead to a proportional increase in profitability Stepova's profitability was 37.5%, which highlights the importance of cost optimisation for seed-focused farms. The study by E. Holt Giménez and A. Shattuck (2011) also confirms that reducing costs without sacrificing productivity is an important component of economic resilience in the face of climate change.

The coefficient of resource use efficiency showed that the highest efficiency was in Stepova (0.0056 t/thousand UAH), which indicates the rational use of resources. This correlates with the findings of M. Sommerville *et al.* (2014), who emphasised the importance of efficient use of resources in agriculture, especially in the context of limited financial resources. This can be attributed to the focus on specialised areas, such as corn seed production, which optimises production costs. This is confirmed

by R. Merino (2020), emphasising that enterprises with specialised activities can achieve higher efficiency through resource optimisation, even if their overall productivity is lower than that of diversified farms. For Svarog West Group, this coefficient was lower (0.0043 t/thousand UAH) due to the scale of operations and wider diversification of production. This structure may require higher costs to support different production areas, making it difficult to achieve maximum efficiency.

However, the study also revealed certain limitations. The impact of climate change on productivity remains a significant factor that makes it difficult to predict economic results in the long term (TOP-10 wheat producing..., 2022). This conclusion is supported by J. Essex *et al.* (2014), who noted that farms that are not adapted to climate change lose some of their productivity despite investments in technology. Without proper adaptation, enterprises may lose some of their efficiency, even when using modern technologies. Thus, this study confirms the need for an integrated approach to agricultural holding management. While investments in technology contribute to increased yields and efficiency, success also depends on the ability of enterprises to adapt to climate and economic changes. The optimal combination of innovative technologies, rational use of resources and adaptation strategies is key to the long-term sustainability and success of agricultural enterprises (Kyfyak *et al.*, 2024). Overall, the findings of this study demonstrate the importance of an integrated approach to agricultural holding management. The use of modern technologies does indeed help to increase productivity, but success also depends on the ability of enterprises to adapt their strategies to external challenges (Pietrzyk, 2022). The findings are in line with international research but also point to some unique aspects, such as the importance of specialisation and effective cost management for profitability. The study also showed that climate change remains a significant factor that makes it difficult to predict economic performance in the long term. This underscores the need to develop comprehensive adaptation strategies aimed at increasing the resilience of enterprises to climate challenges.

Thus, the findings of this study indicate that achieving long-term sustainability in the agricultural sector requires a comprehensive management approach that combines investment in technology, resource optimisation and adaptation to changing conditions. This will allow enterprises to use available resources efficiently and achieve sustainable productivity even in the face of climate and economic challenges. The findings of this study confirm the importance of combining effective governance with technological innovation and adaptation strategies as key factors for ensuring food security and the sustainable development of agricultural enterprises. Both economic and environmental factors need to be addressed to ensure food security. In the future, it is necessary to continue researching the impact of climate change on agricultural production and to develop more flexible management strategies that can ensure stability in a changing environment.

Conclusions

The study was conducted based on three agricultural holdings in Ukraine – Svarog West Group, Stepova and Agroproduct LLC and revealed the importance of investing in modern agricultural technologies to increase agricultural productivity. An analysis of data for three agricultural seasons (2021-2023) showed a clear positive correlation between technology spending and yields, confirming the importance of innovative practices as a key factor in ensuring high productivity. In the case of Svarog West Group, the correlation coefficient between investment and yield reached $r = 0.85$, indicating a high impact of agricultural technology on the results. This underlines the importance of not only the number of financial expenditures but also their adaptation to the specifics of the crops and natural and climatic conditions in which the company operates.

For the Stepova agricultural holding, which specialises in seed production and breeding, the correlation coefficient was slightly lower ($r = 0.72$), indicating a different nature of the impact of the investment. However, this specialisation contributed to high efficiency in the use of resources with an indicator of 0.0056 t/thousand UAH. This suggests that enterprises that focus on the quality of genetic material can maximise the return on investment. This approach confirms the importance of narrow specialisation in the agricultural sector, which allows to optimise of production costs and increases the efficiency of resource use. In terms of profitability, the highest financial performance was demonstrated by Agroproduct LLC, with a profitability of 40%. This demonstrates effective cost management and strategic use of investments in technology. The study showed that even significant expenditures on agricultural technologies can pay off if resources are managed efficiently and production processes are optimised.

Thus, the results of the study underline the need for a comprehensive approach to agricultural holdings management that addresses both economic and environmental aspects. In addition to investing in technology, enterprises should integrate environmental practices to adapt to climate challenges. The prospect of further research is to investigate the long-term contribution of investments in agricultural technologies to the adaptability of agricultural enterprises to climate change and their economic sustainability.

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Conflict of interest

None.

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Стратегія забезпечення продовольчої безпеки в умовах еколого-економічних коливань в Україні

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▸ **Анотація.** Метою цього дослідження було оцінити вплив інвестицій в агротехнології на продуктивність, економічну ефективність і рентабельність агропідприємств. Основний акцент зроблено на аналізі показників врожайності, трьох провідних агрохолдингів України: «Сварог Вест Груп», «Степова» та товариство з обмеженою відповідальністю (ТОВ) «Агропродукт, ЛТД», які функціонують у різних природно-кліматичних умовах. Методологія включала збір даних за три сільськогосподарські сезони (2021-2023 роки), що дало змогу виявити довгострокові тенденції та визначити вплив інвестицій у технології на ключові показники діяльності підприємств. Для оцінки взаємозв'язку між витратами на агротехнології та врожайністю було застосовано кореляційний аналіз із розрахунком коефіцієнтів Пірсона. Економічна ефективність розраховувалася на основі показників рентабельності та коефіцієнта ефективності використання ресурсів, що дозволило порівняти результати між агрохолдингами та виявити особливості управління в різних умовах. Основні результати показали, що інвестиції в агротехнології позитивно впливають на врожайність, хоча їх ефективність залежить від спеціалізації підприємств та умов довкілля. Зокрема, для «Сварог Вест Груп» було виявлено сильний зв'язок між інвестиціями та врожайністю (r=0.85), що підкреслює важливість технологічних інновацій. ТОВ «Агропродукт, ЛТД» продемонструвало найвищий рівень рентабельності (40%), що свідчить про ефективне управління витратами. У свою чергу, «Степова» досягла найвищої ефективності використання ресурсів (0.0056 т/тис. грн) завдяки спеціалізації на насінництві. Отримані результати свідчать про необхідність поєднання технологічних інновацій із адаптацією до кліматичних умов для забезпечення довгострокової ефективності агровиробництва. Ці висновки можуть бути корисними для науковців, управлінців та практиків, які займаються розвитком агропромислового сектору та шукають способи досягнення продовольчої безпеки в умовах змінного клімату

▸ **Ключові слова:** агрономічні технології; рентабельність; врожайність; кліматичні зміни; продовольча безпека; кореляційний аналіз; аграрне управління