**JEL: Q12, Q13, Q16**

***Mykola Vovk[1*], Tetyana Zubro[2], Elvin Omarov[3], Bohdan Kolomiiets[4], Volodymyr Hnydiuk[5]***

*[1]Poltava State Agrarian University*
*[2]University of Economics in Bratislava*
*[3]Simon Kuznets Kharkiv National University of Economics*
*[4]Poltava University of Economics and Trade*
*[5]Higher Educational Institution "Podillia State University"*
*[1,3,4,5]Ukraine*
*[2]Slovakia*
**Corresponding author*

# MODELLING THE EFFICIENCY OF TECHNOLOGICAL MANAGEMENT OF AGRICULTURAL ENTERPRISES IN ECONOMIC SECURITY

***Purpose.*** *The purpose of this study is to develop a model for assessing the efficiency of technological management of agricultural enterprises in the context of ensuring economic security. The study also focuses on the analysis of key factors affecting the efficiency of technological processes, and on the development of tools for improving management technologies in the context of modern economic challenges and risks.*

***Methodology / approach.*** *The study applied a comprehensive approach to modelling the efficiency of technological management at agricultural enterprises. The main tool of analysis was quantitative methods, in particular economic and mathematical modelling, which allowed to assess the impact of various factors on the efficiency of management decisions. Data on financial, economic, technological and production activities of agricultural enterprises were used to build the models. The approach, based on the integration of the methods used, allows not only to assess the current state of technological management, but also to predict possible development scenarios in conditions of economic instability.*

***Results.*** *Modelling of the state of efficiency of technological management in the system of economic security of agricultural enterprises of Poltava, Kyiv and Sumy regions for 2014–2023 was carried out. It was established that agricultural enterprises of Poltava region show consistently high scores, which indicates a strong technical-and-technological potential and the implementation of innovative solutions. Agricultural enterprises of Kyiv region demonstrate a gradual increase in the efficiency of technological management, although their indicators still remain lower than those of enterprises of the Poltava region. Agricultural enterprises of Sumy region have the lowest scores, which indicates serious problems in technical-and-technological development, probably due to an insufficient level of investment. In general, it is necessary to improve the technological management of agricultural enterprises, especially in Kyiv and Sumy regions, in order to ensure stable development of enterprises in the long term.*

***Originality / scientific novelty.*** *The novelty lies in the original authors' comprehensive modelling of the efficiency of technological management of agricultural enterprises through an integrated assessment, which includes technical and technological, production, innovation and management indicators. The originality of the methodology lies in the application of the principal component method to determine weighting factors, which allows identifying key factors that affect technological management and economic security. Taking into account stimulators and destimulators* *when analysing the development of enterprises allows for accurate diagnostics and developing effective strategies for improving management.*

***Practical value / implications.*** *The results can be used in the activities of agricultural enterprises to optimise the processes of making management decisions. The proposed methodology also facilitates the analysis of large volumes of data and increases the accuracy of forecasts, which has a direct impact on strategic planning and competitiveness of the enterprise.*

***Key words:*** *technological management, agribusiness, economic security, risks, innovations, adaptation, strategic planning.*

## 1. INTRODUCTION

Modelling the efficiency of technological management of agricultural enterprises is a key factor in ensuring their stability, competitiveness and adaptability in the face of modern challenges. The agricultural sector of the economy plays a critically important role in the economic security of the state, as it ensures food independence, supports employment in rural regions, forms a significant part of the gross domestic product and contributes to the development of foreign economic relations. That is why the issue of optimising management decisions in technological management is of strategic importance.

Given the growth of global competition and the increasing impact of external threats, agricultural enterprises must adapt to new realities, including changing climate conditions, market instability, resource constraints, and the need to introduce innovations. The use of mathematical models, information systems, and forecasting algorithms allows improving the efficiency of production processes, reducing costs, and increasing the productivity of agricultural production. This contributes not only to increasing the profitability of individual enterprises, but also to strengthening the economic security of the country as a whole.

In the conditions of the russian-Ukrainian war, the issue of adapting technological management to crisis situations is of particular importance. The destruction of logistics chains, the occupation of territories, limited access to resources, energy crises and threats to workers in the agricultural sector of the economy require the development of effective management mechanisms. Modelling allows you to assess possible risks, develop scenarios for the restoration of production, optimise the use of resources and ensure the stable functioning of enterprises even in emergency conditions.

Technological management encompasses a set of management decisions related to the selection, implementation and control of production processes. Its efficiency determines the ability of agricultural enterprises to respond quickly to changes, use advanced technologies, implement automation and digitalisation mechanisms, which is becoming a crucial success factor in modern agricultural production. Intelligent systems for analysing large data sets, forecasting weather conditions, optimising the use of fertilisers and plant protection products allow achieving high results with minimal costs.

An important aspect is also the environmental sustainability of agricultural enterprises. Rational use of land resources, optimisation of agricultural technologies, reduction of negative impact on the environment – all this is possible thanks to effective modelling and implementation of appropriate management decisions. In the long term, this contributes to the formation of a sustainable agroecosystem, ensuring food security and export potential of the country.

The economic security of agricultural enterprises directly depends on their ability to effectively manage risks, plan production processes and develop anti-crisis strategies. In modern conditions, when the agricultural sector of the economy faces the challenges of wartime, global climate change and market instability, the need to implement innovative approaches to technological management becomes obvious.

Therefore, research and implementation of effective technological management models is a strategically important direction for the development of the agricultural sector of the economy. It allows not only to increase the sustainability of individual enterprises, but also to ensure the country's food security, promote post-war economic recovery and the integration of Ukrainian agricultural production into global markets.

The purpose of this study is to develop a model for assessing the efficiency of technological management of agricultural enterprises in the context of ensuring economic security. The study also focuses on the analysis of key factors affecting the efficiency of technological processes, and on the development of tools for improving management technologies in the context of modern economic challenges and risks.

## 2. LITERATURE REVIEW

In general, the topic of modelling the efficiency of technological management of agricultural enterprises in the system of economic security is relevant and actively developing in the scientific literature. Many studies focus on the analysis and improvement of production process management in the agricultural sector of the economy, taking into account modern technologies and innovations, which allows ensuring the stability and competitiveness of enterprises. Modern research focuses on digitalisation, the use of smart technologies, as well as methods of assessing risks and management efficiency. One of the key trends is the integration of sustainable development and economic security in the management of agricultural enterprises. Lezoche et al. (2020) consider future technologies in agri-food supply chains, which directly relates to the efficiency of technological management in agricultural enterprises, in particular in the context of digital innovations that can increase the economic security of enterprises. Yontar (2023) analyses the success factors of implementing blockchain technologies in management in the agricultural sector of the economy, which is an important element for ensuring transparency and security in supply chains, which helps to strengthen the economic security of agricultural enterprises. Di Vaio et al. (2020) focus on the use of artificial intelligence in the agricultural sector of the economy and its role in the sustainable development of business models, which can help in effective management and ensuring the economic security of enterprises. Cherep and Shvets (2020) consider an approach to assessing the impact of internal factors on the anti-crisis management strategy for industrial enterprises, which may be useful for analysing and modelling economic security in the agricultural sector of the economy in times of crisis. Zhao et al. (2020) analyse risks in the supply chain in the agricultural sector of the economy and apply a multifactorial approach to risk management, which is important for ensuring the economic security of agricultural enterprises through optimising risk management. Gutorov and Gutorova (2013) provide theoretical and methodological foundations for assessing the efficiency of management processes, which is useful for analysing and modelling the efficiency of technological management.

Furman et al. (2023) analyse the motivation and incentives of enterprise employees, which is important for increasing the efficiency of management processes and safety in agricultural enterprises. Miranda et al. (2021) investigate circular systems and their management, which directly affects sustainable development and ensuring safety in the agricultural sector of the economy. Kyryliuk et al. (2021) analyse organisational and economic factors for ensuring safety and improving product quality, which is important for increasing the economic security of agricultural enterprises in Ukraine. Saurabh and Dey (2021) study the implementation of blockchain technologies for sustainable agricultural chains, which is important for ensuring economic security, transparency and efficiency in enterprise management. Markina et al. (2022) analyse the management of resource-saving and energy-saving technologies in the agricultural sector of the economy, which can contribute to increasing the economic efficiency and safety of enterprises. Hamidoğlu (2024) use game theory to build a new government-supported food chain model that can help ensure the economic security of enterprises by optimising interactions in supply chains. Pyla et al. (2016) consider methodological approaches to assessing the efficiency of management processes, which is important for modelling the efficiency of technological management in the agricultural sector of the economy. Tell et al. (2016) study innovations in business models of the agricultural sector of the economy, which is important for the adaptation of technological solutions that contribute to ensuring the economic security of enterprises. Yevseitseva et al. (2022) focus on digital marketing as a tool for promoting goods and services in social networks, which can help increase the economic security of agricultural enterprises through marketing strategies. Vashchenko et al. (2023) study the impact of feeding levels on pig growth depending on their genotype, which can be useful for improving the efficiency of technological management in the livestock industry. Balanovska et al. (2020) analyse the profitability of digitalisation of precision agriculture, which is important for improving the efficiency of technological management of agricultural enterprises through the use of the latest technologies. Rayets et al. (2023) identify the role of leadership in stimulating innovation and creative potential of the team, which is important for effective technological management and ensuring economic security in the agricultural sector of the economy.

Cherep et al. (2022) improve the methodological approach to assessing the impact of factors on the mechanism of forming an anti-crisis strategy for enterprises, which can be used to increase the efficiency of management processes and ensure the economic security of agricultural enterprises. Kopishynska et al. (2024) investigate the integrated management of agroecosystem productivity using specialised farm management information systems, which helps optimise decision-making processes and increase yields. Vovk et al. (2022) assess the level of production potential of agricultural enterprises, focusing on factors such as technological advances and resource management to increase productivity and economic stability. Gudz et al. (2020) investigate innovative risk management and insurance technologies for Ukrainian companies in the digital economy, which is necessary to ensure the economic security of agricultural enterprises from various risks. Corallo et al. (2024) consider the role of technology and sustainable development in agri-food supply chain innovations, proposing a new model that ensures the sustainability and profitability of this sector in the face of global challenges. Pilyavoz and Glushchenko (2018) introduce a methodological approach to assess the results of innovative development of enterprises using an integral indicator of their level of innovative development, which is useful for assessing the competitiveness and stability of agricultural enterprises. To assess the innovative capacity of agricultural enterprises, Onegina et al. (2025) developed a comprehensive framework that includes indicators for technological, resource, financial, managerial and human capital dimensions. Zos-Kior et al. (2017) propose a methodology for assessing the globalisation development of countries, which is important for understanding how global market trends affect the economic security of agricultural enterprises. Vovk (2023) examines technological management in the context of ensuring the economic security of agricultural enterprises, focusing on strategies and tools that can reduce risks and increase financial stability in the long term. Krstić et al. (2022) examine the concept of Logistics 4.0 and its application in the circular economy of the agricultural sector, demonstrating how innovative logistics can improve sustainability and efficiency in food production and distribution. Zoria et al. (2022) analyse the theoretical and methodological principles of investment support for the innovative development of agricultural production, focusing on strategies that contribute to sustainable agricultural development and economic security.

Khodakivska et al. (2022) identify areas of sustainable regional development and management of economic security of innovative entrepreneurship, which is important for increasing the stability and development of agricultural enterprises. Kushniruk et al. (2021) consider the role of sustainable development in strengthening food security in EU countries, proposing strategies that can be applied to strengthen the security and sustainability of food systems in Ukraine. Pysarenko et al. (2020) form a marketing logistics business model for the vegetable market, taking into account zonal specialisation aimed at optimising the efficiency of the supply chain in the agricultural sector of the economy. Markina et al. (2022) propose management strategies for forming competitive advantages of enterprises in the agricultural sector of the economy, emphasising the role of innovation and adaptation to the market to ensure the competitiveness and economic security of enterprises. Abbate et al. (2023) examine the digital and sustainable transition of the agricultural sector of the economy, exploring how technology can promote sustainability, innovation and resilience in agricultural enterprises in the face of changing market conditions.

The advantages of the scientific works we reviewed include a comprehensive approach to the management of agricultural enterprises, innovative models and the use of modern technologies to improve the efficiency of the agricultural sector of the economy. The studies offer useful methodologies for assessing the economic security, productivity and competitiveness of enterprises. Scientists also emphasise the importance of sustainable development and investment in innovation to ensure the resilience of the sector in the face of global challenges. However, some works do not take into account specific local conditions, which may limit the applicability of the results in different countries. In addition, the issue of modelling the efficiency of technological management of agricultural enterprises requires a deeper analysis of real cases and more detailed recommendations for practical application.

The hypothesis of the study assumes that technological management in agricultural enterprises is a multifactorial process, and its efficiency depends on an integrated assessment of various components, such as technical and technological, production, innovation and management components. At the same time, the management and innovation components play a key role in forming the overall assessment of efficiency.

## 3. METHODOLOGY

The information base of the study is statistical and primary data for 2014–2023 of 21 agricultural enterprises of Ukraine operating in Poltava, Kyiv and Sumy regions. The choice of enterprises from Poltava, Kyiv and Sumy regions for the study is justified for several key reasons. First, these regions are important agrarian centres of Ukraine, which have a significant contribution to the production of grain, oilseeds, dairy and meat products. They represent different types of economic structures – from large agricultural holdings to medium and small farm enterprises, which allows obtaining a representative sample for analysis. Second, these regions demonstrate different levels of development of technological management and implementation of innovations. Kyiv region, as the administrative and scientific centre of the country, is characterised by a high level of integration of digital solutions and innovative agricultural technologies. Poltava region is known for its powerful agricultural enterprises that actively use modern technologies in production processes, and also has a stable resource base. Sumy region, which borders the aggressor country, faces difficult operating conditions due to military threats, which allows us to investigate how the war affected the economic security of agricultural enterprises and their ability to adapt to crisis challenges. A comprehensive analysis of these regions allows us to obtain a broad idea of the efficiency of technological management, taking into account regional characteristics, the impact of external threats, and the level of innovation implementation. This study will contribute to the development of adaptive management strategies that can be applied in other regions of Ukraine to strengthen the economic security of agricultural enterprises.

It is important to define the authors' position regarding the differences in the concepts of: effectiveness, efficiency and quality of technological management. The concepts of effectiveness, efficiency and quality of technological management are interrelated, but have significant substantive differences that reflect various aspects of technological process management in agricultural enterprises. Effectiveness (performance) in technological management determines the degree of achievement of set goals and fulfilment of planned tasks. It characterises the actual output of production processes, i.e. the volume of products obtained, the level of technological modernisation or the implementation of management initiatives. It is important to understand that high effectiveness does not always indicate optimal use of resources or long-term stability of the enterprise. Efficiency is a broader concept that evaluates not only the final result, but also the methods of achieving it. It reflects the ratio of the results obtained and the resources expended, such as finances, time, energy or labour resources. Effective technological management not only ensures high performance, but also does so with minimal costs and maximum economic and social effect. Therefore, even if an enterprise demonstrates high performance, low efficiency may indicate irrational use of resources or shortcomings in management decisions. The quality of technological management determines the compliance of technological processes, management decisions and implemented innovations with established standards, market requirements and consumer expectations. It covers not only the level of implemented technologies, but also their reliability, stability and adaptability. High quality management of technological processes ensures the long-term competitiveness of agricultural enterprises, minimises risks and increases their resilience in conditions of economic instability. Therefore, performance reflects the achieved indicators, efficiency determines the rational use of resources to obtain them, and quality characterises the level of compliance of processes and management decisions with the strategic goals of the enterprise. The combination of these three components in technological management is the basis for ensuring the stable development of agricultural enterprises and increasing their economic security.

To model the processes of technological management of agricultural enterprises by ensuring economic security, it is proposed to choose a set of indicators that reflect various aspects of the functioning of agricultural enterprises. It is advisable to implement scientific developments in the direction of a comprehensive integrated assessment of technological management of agricultural enterprises in terms of diagnostics of production potential, innovation and management activities (Pyla et al., 2016) and also technical and technological, in order to determine an integrated assessment of the efficiency of technical-and-technological potential management and its impact on ensuring security.

According to the proposed methodology for the efficiency of technological management of agricultural enterprises in the context of ensuring economic security, its integral assessment should be determined, which includes the following sets and subsets of indicators:

- technical-and-technological indicators (subsets: indicators of the technical level of production; indicators of the economic efficiency of the introduction of new technical and organisational innovations; indicators of assessing the technical-and-technological potential of the enterprise; indicators of assessing the economic efficiency of scientific-and-technical progress) (Vovk et al., 2022);

- production indicators (subsets: indicators of the efficiency of the use of fixed assets; indicators of the efficiency of the use of labour resources; indicators of the business activity of the enterprise; indicators of the profitability of production);
- innovation indicators (subsets: economic effect indicators; marketing effect indicators; social effect indicators; environmental effect indicators);
- indicators that characterise the management, innovation and technological processes of the enterprise.

The main stage includes the following stages: selection of a factor according to the formed groups; determination of the significance of the factor's influence for each group and calculation of the factor's weight coefficient for each indicator of the corresponding group; calculation of the actual value for each factor of the corresponding group; refinement of the set of indicators for each group; calculation of the integral indicator of the assessment of the influence of factors for each group; determination of the general integral indicator of the assessment of the influence of internal factors on the use of the mechanism for forming the strategy of an agricultural enterprise (Cherep and Shvets, 2020).

The state of technological management at the enterprise is characterised by many indicators, between which there are correlations. Therefore, the set of such indicators is denoted by G. This set can be represented as a union $G = G_1 \cup G_2 \cup G_3 \cup G_4$, where $G_1, G_2, G_3, G_4$ are sets of technical and technological, production, innovation and management indicators, respectively. In the set $G_1$ of technical-and-technological indicators, in turn, subsets $G_{11}$, $G_{12}$, $G_{13}$ and $G_{14}$ are distinguished, which include indicators of the technical level of production, indicators of the economic efficiency of the introduced new technical and organisational innovations, indicators of the assessment of the technical-and-technological potential of the enterprise and indicators of the assessment of the economic efficiency of scientific and technological research and development. In the set $G_2$ of production indicators, subsets $G_{21}$, $G_{22}$, $G_{23}$ and $G_{24}$ are distinguished, which include indicators of the efficiency of the use of fixed assets, indicators of the efficiency of the use of labour resources, indicators of the business activity of the enterprise and indicators of the profitability of production.

Assessments of the level of innovative development of enterprises, calculated based on a set of indicators and characterising the main parameters of innovative activity, allow us to determine the level of innovative development of an enterprise, analyse its dynamics and, based on this, develop measures aimed at improving the situation (Pilyavoz and Glushchenko, 2018).

The social efficiency of management can be assessed from two perspectives. On the one hand, it is assessed by indicators that reflect the socio-cultural sphere of the organisation's functioning, including the level of labour discipline, the level of stability of the organisation's personnel, the level of development of social infrastructure at the enterprise, the level of working conditions, the level of workplace organisation, etc. On the other hand, by indicators that reflect the impact on achieving production results and meeting market needs; these include labour productivity, salary return, etc. (Gutorov and Gutorova, 2013).

In the set $G_3$ of innovation indicators, subsets $G_{31}$, $G_{32}$, $G_{33}$ and $G_{34}$, can be distinguished, which include, respectively, indicators of economic, marketing, social and environmental effects. The set $G_4$ of management indicators is not divided into subsets. It is generally accepted that it contains one subset $G_{41} = G_4$.

Let $G_{ij} = \{g_{ijk}\}_{k=1}^{m_{ij}}$, where *gijk* are the indicators included in the set $G_{ij}$, and $m_{ij}$ is the number of these indicators. Then $G = \{\{\{g_{ijk}\}_{k=1}^{m_{ij}}\}_{j=1}^{n_i}\}_{i=1}^{4}$, where $n_i$ is the number of subsets into which the set *G* is divided. The $g_{ijk}$ indicators are divided into stimulators and destimulators. The increase in the values of stimulators corresponds to an increase in the level of technological management at the enterprise, and the increase in the values of destimulators corresponds to a decrease in this level. The $g_{ijk}$ indicators selected for the study and their distribution by subsets are shown in Table 1.

*Table 1*

**Indicators for assessing the state of technological management of agricultural enterprises**

| Indicator | Indicator content | Indicator type |
|---|---|---|
| 1 | 2 | 3 |
| | ***Set $G_1$ – technical-and-technological indicators*** | |
| | *Subset $G_{11}$ – indicators of the technical level of production* | |
| $g_{111}$ | Labour capitalisation, UAH/person | Stimulator |
| $g_{112}$ | Production electrification coefficient | Stimulator |
| $g_{113}$ | Production mechanisation coefficient | Stimulator |
| $g_{114}$ | Labour mechanisation coefficient | Stimulator |
| $g_{115}$ | Share of products manufactured on automated equipment, % | Stimulator |
| | *Subset $G_{12}$ – indicators of economic efficiency of new technical and organisational innovations introduced* | |
| $g_{121}$ | Increase in the volume of manufactured products due to technical and organisational innovations, % | Stimulator |
| $g_{122}$ | Share of savings (%) from the introduction of technical and organisational innovations in the total costs of production | Stimulator |
| $g_{123}$ | Indicator of inventive (rationalisation) activity, units/person | Stimulator |
| $g_{124}$ | Indicator of engineering, technical and scientific support, coefficient | Stimulator |
| | *Subset $G_{13}$ – indicators for assessing the technical-and-technological potential of the enterprise* | |
| $g_{131}$ | Technical-and-technological potential of the enterprise, UAH/unit of time | Stimulator |
| $g_{132}$ | Return on assets of the technical-and-technological potential of the enterprise, UAH/UAH-unit of time; | Stimulator |
| | *Subset $G_{14}$ – indicators for assessing the economic efficiency of scientific-and-technical progress* | |
| $g_{141}$ | Efficiency ratio of capital investments | Stimulator |
| $g_{142}$ | Level of expenses for scientific developments in the cost of commodity products, % | Stimulator |
| $g_{143}$ | Level of expenses for the use of scientific and technical achievements in the cost of commodity products, % | Stimulator |
| | ***Set $G_2$ – production indicators*** | |
| | *Subset $G_{21}$ – indicators of the efficiency of the use of fixed assets* | |
| $g_{211}$ | Return on assets, UAH | Stimulator |
| $g_{212}$ | Fixed assets suitability ratio | Stimulator |
| $g_{213}$ | Fixed assets renewal ratio | Stimulator |
| $g_{214}$ | Material return, UAH/UAH | Stimulator |

*Continuation of Table 1*

| 1 | 2 | 3 |
|---|---|---|
| | *Subset $G_{22}$ – labour efficiency indicators* | |
| $g_{221}$ | Labour productivity, thousand UAH/person | Stimulator |
| $g_{222}$ | Staff turnover rate | Destimulator |
| $g_{223}$ | Educational level rate | Stimulator |
| $g_{224}$ | Highly qualified staff turnover rate | Destimulator |
| $g_{225}$ | Knowledge update rate | Stimulator |
| $g_{226}$ | Share of employees engaged in innovation activities in the total number of employees, % | Stimulator |
| | *Subset $G_{23}$ – indicators of business activity of the enterprise* | |
| $g_{231}$ | Asset turnover ratio | Stimulator |
| $g_{232}$ | Current assets turnover ratio | Stimulator |
| $g_{233}$ | Non-current assets turnover ratio | Stimulator |
| $g_{234}$ | Accounts receivable turnover ratio | Stimulator |
| $g_{235}$ | Accounts payable turnover ratio | Stimulator |
| $g_{236}$ | Equity turnover ratio | Stimulator |
| | *Subset $G_{24}$ – production profitability indicators* | |
| $g_{241}$ | Return on current assets, % | Stimulator |
| $g_{242}$ | Return on non-current assets, % | Stimulator |
| $g_{243}$ | Return on equity, % | Stimulator |
| $g_{244}$ | Return on borrowed capital, % | Stimulator |
| $g_{245}$ | Return on invested capital, % | Stimulator |
| $g_{246}$ | Return on commercial products, % | Stimulator |
| $g_{247}$ | Return on operating activities, % | Stimulator |
| $g_{248}$ | Return on fixed assets, % | Stimulator |
| $g_{249}$ | Return on sales, % | Stimulator |
| $g_{24(10)}$ | Return on investments, % | Stimulator |
| | ***Set $G_3$ – innovation indicators*** | |
| | *Subset $G_{31}$ – economic effect indicators* | |
| $g_{311}$ | Net present income, thousand UAH | Stimulator |
| $g_{312}$ | Innovation profitability, % | Stimulator |
| $g_{313}$ | R&D investment efficiency, % | Stimulator |
| $g_{314}$ | Innovation income per employee, thousand UAH/person | Stimulator |
| | *Subset $G_{32}$ – Marketing effect indicators* | |
| $g_{321}$ | Enterprise reputation index, coefficient | Stimulator |
| $g_{322}$ | Sales growth, % | Stimulator |
| $g_{323}$ | Strengthening market positions, % of market | Stimulator |
| $g_{324}$ | Increasing share of potential customers, % | Stimulator |
| | *Subset $G_{33}$ – social impact indicators* | |
| $g_{331}$ | Additional jobs, units | Stimulator |
| $g_{332}$ | Level of wage growth, % | Stimulator |
| $g_{333}$ | Development of social infrastructure, % of the total budget | Stimulator |
| $g_{334}$ | Level of employee qualifications, % of employees by qualification categories (workers, specialists, managers) | Stimulator |
| $g_{335}$ | Increased investment attractiveness, % investment growth per year | Stimulator |
| | *Subset $G_{34}$ – Environmental impact indicators* | |
| $g_{341}$ | Facility environmental efficiency coefficient | Stimulator |
| $g_{342}$ | Waste capacity coefficient | Destimulator |
| $g_{343}$ | Production environmental efficiency coefficient | Stimulator |

*Continuation of Table 1*

| 1 | 2 | 3 |
|---|---|---|
| | ***Set G4 – management indicators*** | |
| $g_{411}$ | Coefficient of implementation of the plan for the implementation of new technological projects | Stimulator |
| $g_{412}$ | Coefficient of the degree of manageability of technological projects | Stimulator |
| $g_{413}$ | Coefficient of informatisation of management of technical-and-technological business processes | Stimulator |
| $g_{414}$ | Coefficient of quality of implemented technologies | Stimulator |
| $g_{415}$ | Coefficient of involvement of employees in the implementation of innovative technologies at enterprises | Stimulator |
| $g_{416}$ | Coefficient of provision of enterprises with objects of intellectual property rights for which there are relevant documents | Stimulator |
| $g_{417}$ | Coefficient of modernisation and reconstruction of the scientific and technological and research and industrial base of enterprises | Stimulator |
| $g_{418}$ | Coefficient of creation of new jobs for management of innovation projects | Stimulator |
| $g_{419}$ | Coefficient of the level of profitability of employees involved in the implementation of technological projects | Stimulator |
| $g_{41(10)}$ | Coefficient of the impact of technological projects on the greening of production | Stimulator |
| $g_{41(11)}$ | Coefficient of the frequency of implementation of innovations at the enterprise | Stimulator |
| $g_{41(12)}$ | Coefficient of satisfaction with the scientific and technical development of the enterprise | Stimulator |
| $g_{41(13)}$ | Coefficient of accessibility to new scientific-and-technical developments | Stimulator |

*Source:* authors' development.

For each subset $G_{ij}$, a complex integral assessment of the corresponding aspect of technological management is determined. To calculate such assessments, statistical and primary data on the values of $g_{ijk}$ indicators for 21 agricultural enterprises of three regions of Ukraine were used. To refer to the enterprises of these regions, the variable q was used, which takes the values $q = 1$ for enterprises of Poltava region, $q = 2$ for enterprises of Kyiv region, $q = 3$ for enterprises of Sumy region. The value of the $g_{ijk}$ indicator for the $q$-th enterprise in the $t$-th year of the retrospective period is denoted by $g_{ijk}(q, t)$.

To obtain an integral estimate $w_{ij}$ corresponding to the set of indicators $G_{ij}$, the indicators $g_{ijk}$ included in this set must be normalised, i.e. replaced with dimensionless indicators $r_{ijk}$ that would linearly depend on $g_{ijk}$ and vary in the interval [0;1], and the value $r_{ijk} = 1$ would correspond to the best value of the indicator $g_{ijk}$.

For stimulators, normalisation is performed according to the formula (1):

$$r_{ijk}(q,t) = \frac{g_{ijk}(q,t) - g_{ijk}^{min}}{g_{ijk}^{max} - g_{ijk}^{min}}, \tag{1}$$

and for destimulators – according to the formula (2):

$$r_{ijk}(q,t) = \frac{g_{ijk}^{max} - g_{ijk}(q,t)}{g_{ijk}^{max} - g_{ijk}^{min}}, \tag{2}$$

where $g_{ijk}^{max}$ and $g_{ijk}^{min}$ are the maximum and minimum values of the $g_{ijk}$ indicator.

The integral estimate $w_{ij}$ is a linear combination of the normalised indices $r_{ijk}$ (3):

$$w_{ij}(q,t) = \sum_{k=1}^{m_{ij}} \alpha_{ijk} r_{ijk}(q,t), \tag{3}$$

where $w_{ij}(q,t)$ – the value of the integral estimate $w_{ij}$ for the $q$-th region in the $t$-th year of the retrospective period, $\alpha_{ijk}$ – the weight coefficient.

Having determined the importance of the influence of factors for each group, it is necessary to calculate the actual value for each factor of the corresponding group. Calculating the actual value for each factor allows calculating the integral indicators for each group of factors (Cherep et al., 2022).

The weighting coefficients $\alpha_{ijk}$ were determined by the modified principal component method. The formulas determined in this way for obtaining integral estimates are given in Table 2.

*Table 2*

**Formulas for obtaining integral assessments of aspects of technological management of agricultural enterprises corresponding to sets of indicators $G_{ij}$**

| Set of indicators | Formula for obtaining an integral estimate |
|---|---|
| $G_{11}$ | $w_{11} = 0.095004r_{111} + 0.003916r_{112} + 0.325367r_{113} + 0.251502r_{114} + 0.325456\ r_{115}$ |
| $G_{12}$ | $w_{12} = 0.1250036r_{121} + 0.000890r_{122} + 0.598712r_{123} + 0.275530r_{124}$ |
| $G_{13}$ | $w_{13} = 0.4878636r_{131} + 0.5132226r_{132}$ |
| $G_{14}$ | $w_{14} = 0.037195r_{141} + 0.541372r_{142} + 0.4235r_{143}$ |
| $G_{21}$ | $w_{21} = 0.458294r_{211} + 0.458294r_{212} + 0.048939r_{213} + 0.035745r_{214}$ |
| $G_{22}$ | $w_{22} = 0.247109r_{221} + 0.137382r_{222} + 0.195481r_{223} + 0.167708r_{224} + 0.253305r_{225} + 0.0032r_{226}$ |
| $G_{23}$ | $w_{23} = 0.388478r_{231} + 0.337168r_{232} + 0.0424r_{233} + 0.142455r_{234} + 0.046326r_{235} + 0.055466r_{236}$ |
| $G_{24}$ | $w_{24} = 0.1774r_{241} + 0.066316r_{242} + 0.072236r_{243} + 0.081316r_{244} + 0.160156r_{245} + 0.03691r_{246} +$ $+0.142606r_{247} + 0.000269r_{248} + 0.254620r_{249} + 0.02254r_{24(10)}$ |
| $G_{31}$ | $w_{31} = 0.28128r_{311} + 0.211242r_{312} + 0.206125r_{313} + 0.301414r_{314}$ |
| $G_{32}$ | $w_{32} = 0.30868r_{321} + 0.128092r_{322} + 0.247905r_{323} + 0.316732r_{324}$ |
| $G_{33}$ | $w_{33} = 0.217819r_{331} + 0.174149r_{222} + 0.276881r_{333} + 0.158424r_{334} + 0.182890r_{335}$ |
| $G_{34}$ | $w_{34} = 0.454356r_{341} + 0.396262r_{342} + 0.179415r_{343}$ |
| $G_{41}$ | $w_{41} = 0.06669r_{411} + 0.07096r_{412} + 0.086264r_{413} + 0.012109r_{414} + 0.097881r_{415} + 0.111977r_{416} +$ $+ 0.052634r_{417} + 0.116668r_{418} + 0.1264524r_{419} + 0.094147r_{41(10)} + 0.064604r_{41(11)} +$ $+ 0.0432107r_{41(12)} + 0.074658r_{41(13)}$ |

*Source:* prepared based on enterprises' data and the source (State Statistics Service…, 2024).

All calculations were carried out using Excel software. The determined integral estimates $w_{ij}$ are the basis for integral estimates of a higher level of integration. Such estimates are estimates of the technical and technological, production, innovation and managerial components of technological management.

## 4. RESULTS

***4.1. Integral assessment of the technical-and-technological component of technological management of agricultural enterprises.*** The estimate $W_1$ of the technical-and-technological component is determined by the indicators from the set $G_1$.

Since $G_1 = \bigcup_{j=1}^{4} G_{1j}$, and the sets $G_{1j}$ correspond to the integral estimates $w_{1j}$, the estimate $W_1$ can be determined as a linear combination of the estimates $w_{1j}$, i.e. the equality holds (4):

$$W_1(q,t)=\sum_{j=1}^{4}\beta_{1j}w_{1j}(q,t) \quad (4)$$

The weighting coefficients $\beta_{1j}$ are determined by the modified principal component method. The covariance matrix of the indicators $w_{1j}$ has the following form (5):

$$K_1=\begin{Vmatrix} 0.08163 & 0.04430 & 0.05900 & 0.06936 \\ 0.04430 & 0.04297 & 0.03889 & 0.04363 \\ 0.05900 & 0.03889 & 0.06357 & 0.06585 \\ 0.06936 & 0.04363 & 0.06585 & 0.07798 \end{Vmatrix} \quad (5)$$

To determine its maximum eigenvalue, the equation was solved (6):

$$det(K_1-\lambda E)=0, \quad (6)$$

where $E$ is the identity matrix, $det(K_1-\lambda E)$ is the determinant of the matrix $K_1-\lambda E$. The maximum root of this equation $\lambda_1$ = 0.2396. The eigenvector $A_1$ corresponding to this value is determined from equality (7):

$$K_1A_1=\lambda_1A_1. \quad (7)$$

Based on this, we obtain $A_1$ = (0.5565; 0.3575; 0.4988; 0.5637). The weighting coefficients $\beta_{1j}$ are chosen to be proportional to the squares of the coordinates of the vector $A_1$. As a result, we obtain:

$\beta_{11}$ = 0.308780; $\beta_{12}$ = 0.127292; $\beta_{13}$ = 0.257805; $\beta_{14}$ = 0.336631.

Therefore, the integral assessment of the technical-and-technological component of technological management is determined by the formula (8):

$$W_1 = 0.308780w_{11} + 0.127292w_{12} + 0.257805w_{13} + 0.336631w_{14}. \quad (8)$$

Thus, the formation of an integrated assessment of the technical-and-technological component of technological management is most influenced by indicators of the technical level of production and indicators of the assessment of the economic efficiency of scientific-and-technical progress. The average values of this integrated assessment for the enterprises studied are given in Table 3. These results reflect the integrated activities of agricultural enterprises in Poltava, Kyiv and Sumy regions.

*Table 3*

**Integral assessments of the technical-and-technological component of technological management of agricultural enterprises for 2014–2023**

| Area of location of enterprises | Years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Poltava | 0.5852 | 0.5875 | 0.6213 | 0.6360 | 0.6302 | 0.6412 | 0.6579 | 0.6758 | 0.5007 | 0.5186 |
| Kyiv | 0.4499 | 0.4585 | 0.5201 | 0.5560 | 0.5622 | 0.5734 | 0.5892 | 0.6198 | 0.4058 | 0.4121 |
| Sumy | 0.2549 | 0.2407 | 0.3181 | 0.3784 | 0.3832 | 0.3359 | 0.3675 | 0.4049 | 0.1405 | 0.2115 |

*Source:* prepared on the basis of enterprises' data and own calculations.

Analysis of the dynamics of integral assessments of the technical-and-technological component of technological management of agricultural enterprises indicates a general trend towards increasing the efficiency of technological management of enterprises by 2021, which reflects the improvement of management and technological processes. In the Poltava region, enterprises show the highest integral assessments throughout the analysed period, which indicates a consistently high level of technical-and-technological potential and the implementation of effective solutions.

Kyiv region shows a gradual increase in scores, indicating an improvement in technological management at enterprises, although the level of efficiency remains lower than in Poltava, which may be a consequence of a lower intensity of innovation processes or differences in the resource provision of enterprises in the region. Sumy region is marked by the lowest indicators among the three regions, indicating significant difficulties in the technical-and-technological development of enterprises, which may be due to a weaker level of material and technical base or insufficient investment in the latest technologies.

A significant decrease in estimates in 2022–2023, typical for enterprises in all regions, reflects the impact of crisis phenomena that could lead to a reduction in production, disruption of logistics chains, or aggravation of resource supply problems. The decrease in the efficiency of technological process management during this period indicates the vulnerability of agricultural enterprises to external economic and social factors.

The data in Table 3 emphasise the importance of developing the technical-and-technological potential of enterprises for their resilience in the face of challenges and crisis situations. The difference between regions indicates an uneven distribution of resources and opportunities for enterprises, which creates additional tasks for regional policy and strategic planning. The results of the analysis emphasise the need to improve technological management at enterprises in all regions to ensure their resilience and competitiveness in the long term.

***4.2. Integral assessment of the production component of technological management of agricultural enterprises.*** The estimate $W_2$ of the production component is determined based on the indicators from the set $G_2$.

Since $G_2 = \bigcup_{j=1}^{4} G_{2j}$, and the sets $G_{2j}$ correspond to the integral estimates $w_{2j}$, the estimate $W_2$ is a linear combination of the estimates $w_{2j}$, i.e. (9):

$$W_2(q,t) = \sum_{j=1}^{4} \beta_{2j} w_{2j}(q,t) . \tag{9}$$

The weighting coefficients $\beta_{2j}$ are determined by the modified principal component method. The covariance matrix of the $w_{2j}$ indicators is as follows (10):

$$K_2 = \begin{Vmatrix} 0.00032 & -0.00089 & -0.00077 & 0.00035 \\ -0.00089 & 0.02223 & 0.01155 & -0.00433 \\ -0.00077 & 0.01155 & 0.03582 & -0.01488 \\ 0.00035 & -0.00413 & -0.01488 & 0.03147 \end{Vmatrix} \tag{10}$$

Its maximum eigenvalue $\lambda_2 = 0.0539$. The corresponding eigenvector $A_2 = (0.0198; -0.3596; -0.7349; 0.5866)$. The weighting coefficients $\beta_{2j}$ are chosen to be proportional to the squares of the coordinates of the vector $A_2$. Based on this, we obtain:

$$\beta_{21} = 0.000453; \beta_{22} = 0.129594; \beta_{23} = 0.539609; \beta_{24} = 0.342468.$$

Therefore, the integral assessment of the production component of technological management is determined by the formula (11):

$$W_2 = 0.000453w_{21} + 0.129594w_{22} + 0.539609w_{23} + 0.342468w_{24}. \quad (11)$$

The formation of an integrated assessment of the production component of technological management is most influenced by the indicators of the enterprise's business activity and indicators of production profitability. The values of this assessment for the agricultural enterprises studied are given in Table 4.

*Table 4*

**Integral assessments of the production component of technological management of agricultural enterprises for 2014–2023**

| Area of location of enterprises | Years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Poltava | 0.4278 | 0.5697 | 0.4969 | 0.3940 | 0.4874 | 0.5439 | 0.4241 | 0.4115 | 0.2671 | 0.4102 |
| Kyiv | 0.2429 | 0.3484 | 0.2797 | 0.2725 | 0.2894 | 0.2669 | 0.2218 | 0.2612 | 0.3619 | 0.2126 |
| Sumy | 0.3042 | 0.3099 | 0.2313 | 0.2614 | 0.3142 | 0.2839 | 0.4052 | 0.3345 | 0.3136 | 0.3166 |

*Source:* prepared on the basis of enterprises' data and own calculations.

Analysis of the dynamics of the integral estimates of the production component of technological management of agricultural enterprises for 2014–2023 indicates significant regional differences and changes in the efficiency of production processes of enterprises over time. Enterprises of Poltava region demonstrate the highest integral estimates among the three regions, especially in 2015, when their indicator reached 0.5697, which is the highest for the entire period. However, after that, there is a decline, with a significant decrease to 0.2671 in 2022, which may be associated with external crisis factors. At the same time, in 2023, enterprises of Poltava region showed signs of recovery, rising to the level of 0.4102.

In Kyiv region, enterprises demonstrated significantly lower integral scores than in Poltava region. The highest indicator was recorded in 2015 (0.3484), but in other years the scores varied within 0.2126–0.2894. The decrease in 2023 to 0.2126 is especially noticeable, indicating an increase in problems in the production activities of enterprises, which could be associated with a lack of resources or instability in the region.

Enterprises of Sumy region demonstrate the most stable dynamics among the analysed regions. Their integral scores remain in a relatively narrow range of 0.2313–0.4052. The highest indicator was achieved in 2020, when the integral score was 0.4052, which may indicate a temporary improvement in the production base or the efficiency of management decisions. However, in 2022 the value decreased again to 0.3136, although in 2023 it stabilised at 0.3166.

In general, enterprises in all three regions demonstrate instability in the dynamics of indicators, which may be due to the influence of external factors, such as the economic crisis or military actions, which affected the availability of resources and production capabilities. Poltava enterprises show the highest average level of assessments for the period, which indicates their leading position in the field of production management. At the same time, the values of enterprises in Kyiv and Sumy regions indicate the need to intensify measures to modernise production processes, increase the efficiency of resource use and introduce the latest technologies. Such results emphasise the need for targeted regional support to strengthen the production component of technological management of enterprises.

***4.3. Integral assessment of the innovative component of technological management of agricultural enterprises.*** The score $W_3$ of the innovative component is determined based on the indicators from the set $G_3$. The covariance matrix of the $w_{3j}$ indicators has the following form (12):

$$K_3 = \begin{Vmatrix} 0.05668 & 0.01572 & 0.03306 & 0.03306 \\ 0.01572 & 0.06273 & 0.04532 & 0.03714 \\ 0.03306 & 0.04532 & 0.05105 & 0.04651 \\ 0.03163 & 0.02814 & 0.03751 & 0.04543 \end{Vmatrix} \qquad (12)$$

Its maximum eigenvalue $\lambda_3 = 0.1551$. The corresponding eigenvector $A_3 = (0.4598; 0.5363; 0.578; 0.455)$. The weighting coefficients $\beta_{3j}$, as in the previous cases, are chosen to be proportional to the squares of the coordinates of the vector $A_3$. The results are given below:

$$\beta_{31} = 0.202420; \beta_{32} = 0.277992; \beta_{33} = 0.323624; \beta_{24} = 0.199025.$$

Therefore, the integral assessment of the innovative component of technological management is determined by the formula (13):

$$W_3 = 0.202420w_{31} + 0.277992w_{32} + 0.323624w_{33} + 0.199025w_{34}. \qquad (13)$$

The formation of an integrated assessment of the innovative component of technological management for agricultural enterprises is most influenced by indicators of social effect and indicators of marketing effect. The values of this assessment for the agricultural enterprises studied are given in Table 5.

*Table 5*

**Integral assessments of the innovative component of technological management of agricultural enterprises for 2014–2023**

| Area of location of enterprises | Years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Poltava | 0.4509 | 0.4893 | 0.4998 | 0.5734 | 0.6564 | 0.7726 | 0.8520 | 0.9312 | 0.3798 | 0.4302 |
| Kyiv | 0.4167 | 0.4485 | 0.4886 | 0.5150 | 0.5448 | 0.5798 | 0.6355 | 0.7031 | 0.3542 | 0.3872 |
| Sumy | 0.2389 | 0.2503 | 0.3209 | 0.3801 | 0.4538 | 0.5192 | 0.5711 | 0.6348 | 0.1147 | 0.1912 |

*Source:* prepared on the basis of enterprises' data and own calculations.

The results of the analysis of the dynamics of the integral assessments of the innovative component of technological management of agricultural enterprises for the period 2014–2023, again, indicate significant regional differences in the level of innovation implementation at enterprises, as well as noticeable changes in these indicators during the analysed period. Enterprises of the Poltava region demonstrate the most progressive development of the innovative component, reaching peak values in 2021 with an integral assessment of 0.9312, which indicates the effective implementation of innovative approaches in technological management, which could be the result of significant investments in the latest technologies and active innovative activity of enterprises in the region.

Enterprises of Kyiv region also demonstrate stable development of innovative potential, although their indicators are inferior to Poltava region. Positive dynamics during 2014–2021 indicate a gradual increase in innovative activity of enterprises, which contributed to their adaptation to changes in market conditions and technological environment. The highest level of innovative component for Kyiv region was also recorded in 2021, after which a sharp decrease is observed in 2022–2023, which, again, is likely due to external crisis factors.

In Sumy region, enterprises demonstrate the lowest integral assessments of the innovation component among the analysed regions. During 2014–2021, there has been a gradual increase in indicators, which indicates a certain improvement in the innovative activity of enterprises, but the pace of this development is much slower than in Poltava and Kyiv regions. The drop in integral assessments in 2022 to the level of 0.1147 indicates a critical reduction in the innovative activity of enterprises, which is likely due to the impact of difficult economic and social conditions.

In general, enterprises in all three regions demonstrated positive dynamics of the development of the innovation component by 2021, however, the crisis of 2022–2023, caused by the russian-Ukrainian war, significantly affected their innovation activity. This indicates the need to support enterprises in the direction of introducing the latest technologies, preserving scientific and technical potential and developing strategies for adapting to crisis conditions. The results obtained emphasise the importance of innovation as a key factor in increasing the competitiveness of agricultural enterprises.

***4.4. Integral assessment of the managerial component of technological management of agricultural enterprises.*** Since the managerial component of technological management is determined only by indicators from one set $G_4$, which is not divided into subsets, the integral score $W_4$ of this component is equal to the integral score $w_{41}$. The formation of this integral score is most influenced by the level of profitability of employees involved in the implementation of technological projects, the creation of new jobs for the management of innovative projects, and the provision of enterprises with intellectual property rights. The values of this score for the enterprises studied are given in Table 6.

Based on the analysis of the dynamics of the integral assessments of the management component of technological management of agricultural enterprises for 2014–2023, significant regional differences in the efficiency of management at enterprises were identified, as well as positive dynamics in the development of management processes by 2021. Enterprises of the Kyiv region demonstrate the highest integral assessments among the analysed regions, which indicates the high efficiency of management decisions, a developed management structure and active implementation of modern management practices. In 2021, enterprises of this region reached the maximum level of the management component with an indicator of 0.9795, which emphasises their competitive advantage. Despite the decline in 2022–2023, the assessments remain at a high level, which indicates the stability of the management system.

*Table 6*

**Integral assessments of the managerial component of technological management of agricultural enterprises for 2014–2023**

| Area of location of enterprises | Years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Poltava | 0.4881 | 0.5517 | 0.5825 | 0.6294 | 0.6877 | 0.7287 | 0.7791 | 0.8231 | 0.4001 | 0.4588 |
| Kyiv | 0.7986 | 0.8252 | 0.8580 | 0.8889 | 0.8896 | 0.9284 | 0.9495 | 0.9795 | 0.7613 | 0.7962 |
| Sumy | 0.5599 | 0.5816 | 0.5940 | 0.6522 | 0.6773 | 0.7080 | 0.7646 | 0.8089 | 0.4517 | 0.4946 |

*Source:* prepared on the basis of enterprises' data and own calculations.

Enterprises of Poltava region demonstrate a gradual increase in the management component during the analysed period, in particular, from an indicator of 0.4881 in 2014 to 0.8231 in 2021. Such development indicates an improvement in management processes and a gradual modernisation of approaches to technological management. However, in 2022 there is a significant decrease to 0.4001, which indicates the impact of crisis factors on the management efficiency of enterprises.

Enterprises of Sumy region have average indicators among the analysed regions, demonstrating stable development until 2021. The scores increased from 0.5599 in 2014 to 0.8089 in 2021, which indicates the intensification of management activities and gradual improvement of the management system. However, in 2022 there was also a significant decrease to 0.4517, which may be associated with external constraints that affected the management activities of enterprises.

The data in Table 6 demonstrate that enterprises in all three regions were significantly affected by crisis conditions in 2022–2023, which reduced the efficiency of management processes. However, the positive dynamics up to this period indicate significant potential for enterprises in building a modern management system. Improving management decisions and implementing innovative methods are key factors for restoring and strengthening the positions of enterprises in the long term.

***4.5. Comprehensive integral assessment of technological management at agricultural enterprises.*** The complex integral assessment of technological management at agricultural enterprises was obtained as a linear combination of assessments $W_1$, $W_2$, $W_3$ and $W_4$, i.e. it has the form $W = \sum_{i=1}^{4} \beta_i w_i$. The weighting coefficients $\beta_i$ were determined by the modified principal component method.

The covariance matrix of the $W_i$ indicators has the following form (14).

$$K = \begin{Vmatrix} 0.02019 & 0.00725 & 0.02059 & 0.02510 \\ 0.00725 & 0.01111 & 0.01138 & 0.00571 \\ 0.02059 & 0.01138 & 0.03847 & 0.02896 \\ 0.02510 & 0.00571 & 0.02896 & 0.07900 \end{Vmatrix} \quad (14)$$

Its maximum eigenvalue $\lambda = 0.1145$. The corresponding eigenvector $A = (0.3528; 0.1235; 0.4667; 0.823)$. The weights $\beta_i$ are chosen to be proportional to the squares of the coordinates of the vector $A$. The results are given below:

$$\beta_1 = 0.118512;\ \beta_2 = 0.022882;\ \beta_3 = 0.209575;\ \beta_4 = 0.670969.$$

Therefore, the complex integral assessment of technological management is determined by the formula (15):

$$W = 0.118512w_1 + 0.022882w_2 + 0.209575w_3 + 0.670969w_4. \quad (15)$$

The formation of this integral assessment is most influenced by the assessments of the managerial and innovative components of technological management. The values of the comprehensive integral assessment of technological management for the studied agricultural enterprises are given in Table 7.

*Table 7*

**Comprehensive integral assessments of technological management of agricultural enterprises for 2014–2023**

| Area of location of enterprises | Years | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
| Poltava | 0.4909 | 0.5431 | 0.5687 | 0.6154 | 0.6718 | 0.7251 | 0.7754 | 0.8230 | 0.4144 | 0.4680 |
| Kyiv | 0.6708 | 0.6973 | 0.7338 | 0.7638 | 0.7714 | 0.8054 | 0.8322 | 0.8703 | 0.6309 | 0.6633 |
| Sumy | 0.4538 | 0.4689 | 0.4999 | 0.5582 | 0.5914 | 0.6194 | 0.6729 | 0.7190 | 0.3453 | 0.4028 |

*Source:* prepared on the basis of enterprises' data and own calculations.

Table 7 shows the values of the estimates characterising the level of technological management of agricultural enterprises at different stages of development for the period from 2014 to 2023. In particular, for the Poltava region, the estimates for the entire period vary from 0.4909 in 2014 to 0.4680 in 2023. The highest level of technological management was recorded in 2021 – 0.8230, while the value in 2022 decreased to 0.4144. In the Kyiv region, there has been a steady increase in estimates for most years, starting from 0.6708 in 2014 and reaching 0.8703 in 2021, which is the highest value for the entire period. However, after that, there is a slight decrease in the estimate in 2022 and 2023 – to 0.6309 and 0.6633, respectively. Sumy region has a gradual increase in estimates from 0.4538 in 2014 to 0.7190 in 2021, after which a noticeable decrease is observed in 2022 and 2023 to values of 0.3453 and 0.4028. In general, a trend towards an increase in technology management was recorded in most regions until 2021, after which some regions saw a decrease in scores in 2022–2023.

The results of the assessment of the efficiency of technological management can help identify bottlenecks in technological processes and internal operations of agricultural enterprises. A practical step is the implementation of modern project management methods, which will reduce the time to complete tasks, increase flexibility and efficiency in working with technologies. Enterprises can use these results to establish partnerships with international companies, which will allow them to gain access to the latest technologies and expand sales markets. Policy recommendations include creating conditions for global cooperation in the field of technology through international agreements, forums and other platforms. In view of the assessment of the efficiency of technological management at the national level, it is important to develop a policy that will stimulate investment in agricultural technologies, which may include tax breaks for enterprises implementing the latest technologies, as well as the creation of infrastructure to support start-ups and small innovative enterprises. National policy should promote the development of technological clusters, which will ensure the sustainable development of the agricultural sector of the economy through support for innovation.

## 5. DISCUSSION

The proposed methodology for modelling the efficiency of technological management of agricultural enterprises, unlike those existing in the scientific world, is based on an integral assessment and has significant advantages in terms of its universality, comprehensiveness and ability to identify key problem areas in the functioning of enterprises. The results obtained develop and improve certain provisions that are reflected in scientific works. Lezoche et al. (2020) in their study pay significant attention to the concept of "Agri-food 4.0", which involves the digitalisation and automation of production processes. In contrast to this approach, the methodology we propose focuses not only on technological aspects, but also on an integral analysis of the management, innovation and production components. However, the implementation of "Agri-food 4.0" technologies could increase the efficiency of technological management, which should be taken into account in further research. Di Vaio et al. (2020) emphasise the impact of COVID-19 on the modification of business models in the agricultural sector of the economy. Our analysis confirms the significant impact of crisis events, particularly in 2022–2023, but does not detail their specifics. Additional emphasis on adapting management decisions to crisis conditions, as done in the work of Di Vaio et al. (2020), could improve the proposed methodology. Zhao et al. (2020) analyse risks in agri-food supply chains using a multi-method approach. In our methodology, risks are taken into account indirectly through the analysis of disincentives, but there is no in-depth analysis of risks in supply chains. Integrating risk assessment methods from the work of Zhao et al. (2020) could strengthen the diagnostic capabilities of our approach. Miranda et al. (2021) propose to assess agri-food systems from the perspective of the circular economy. This approach is promising and can complement our methodology, especially to take into account the impact of environmental factors. Incorporating sustainability indicators into the proposed model could provide multidimensionality. Saurabh and Dey (2021) analyse the possibilities of implementing blockchain technologies in agri-food chains. In our methodology, digitalisation technologies are not yet considered as a separate factor, but blockchain could serve as a tool for improving management processes and increasing the transparency of assessments. Markina et al. (2021) emphasise the importance of resource-saving technologies in enterprise restructuring. The methodology we propose can be adapted to take into account such technologies as efficiency drivers, which will contribute to a greater environmental orientation of assessments. Rayets et al. (2023) discuss the role of leadership in stimulating innovative activity. In our work, the management component takes into account social aspects, but does not focus on leadership as a separate factor. Expanding the model to assess the impact of leadership could improve its adaptability to the real conditions of enterprises. Krstić et al. (2022) investigate logistics 4.0 and its contribution to the transition to a circular economy in the agricultural sector. The inclusion of indicators related to the efficiency of logistics processes could increase the accuracy of the integrated assessment of our methodology. Abbate et al. (2023) emphasise the need for a digital and sustainable transition of the agricultural sector of the economy. Their approach is consistent with our emphasis on the innovation component, but offers a broader perspective that should be integrated into further research.

Discussion of scientific works related to our methodology showed significant potential for its improvement by integrating modern approaches to agricultural enterprise management. The analysis confirmed the relevance and feasibility of a multidimensional approach that takes into account technical, innovative, production and managerial components; however, it revealed certain limitations, in particular, insufficient consideration of environmental, social and risk aspects. The methodology we proposed is well in line with modern trends in the field of digitalisation, smart technologies, logistics 4.0 and circular economy, but requires adaptation to take into account the specifics of these approaches. The inclusion of resource-saving technologies, risk assessment in supply chains, the role of leadership and innovation activities can improve the diagnostic capabilities and flexibility of our model. Research also confirmed the significant impact of crisis phenomena on the efficiency of agricultural enterprises, emphasising the need to develop tools for adapting to external challenges. Integrating insurance mechanisms and risk management into our methodology can help increase the resilience of enterprises to unstable conditions. Thus, our proposed methodology has the potential for further development to become a more universal tool for analysis and management, taking into account not only the current state of agricultural enterprises, but also the long-term prospects for their sustainable development in the face of modern challenges.

## 6. CONCLUSIONS

The overall result of this study is a systematic analysis and assessment of the efficiency of technological management of agricultural enterprises, which allowed us to identify key factors that determine their technological capability and competitiveness. Analysis of the technical, technological, production, innovation and management components of technological management of agricultural enterprises in Poltava, Kyiv and Sumy regions for 2014–2023 showed significant regional differences in the dynamics of assessments. At the same time, there was a common positive trend towards increasing the efficiency of technological management of agricultural enterprises in most regions until 2021, after which a decrease in assessments was recorded. The decrease in assessments in 2022–2023 was caused by the impact of crisis economic and social factors, in particular the russian-Ukrainian war and economic difficulties. Since the results of the study correspond to the main assumptions, it can be noted that the hypothesis is confirmed. This is confirmed by mathematical calculations of weights for various components and their impact on the overall efficiency of technological management. The results confirmed the assumption that to increase the efficiency of technological management in agricultural enterprises, special attention should be paid to the managerial and innovative components. The technical-technological and production components have less influence, but their role is also important, albeit to a lesser extent. The results of testing this hypothesis can become the basis for developing recommendations for agricultural enterprises to improve technological management. For example, enterprises can focus on improving management strategies, developing innovative projects and applying the latest management technologies to achieve higher levels of productivity and economic security. Based on the analysis, recommendations were formulated aimed at improving technological processes, developing innovations, optimising resources and ensuring sustainable economic growth.

The obtained results indicate the need for active measures to modernise and improve technological management at agricultural enterprises of all regions. Enterprises of Poltava region show a consistently high level of integral assessments, but even they experienced significant difficulties during the crisis period. For enterprises of Kyiv and Sumy regions, measures to increase the efficiency of production and innovation processes are relevant to ensure their sustainability in the future.

## 7. LIMITATIONS AND FUTURE RESEARCH

This study on modelling the efficiency of technological management of agricultural enterprises in the economic security system has certain limitations due to data availability, choice of methodological approaches and assumptions. The limited amount of information on the financial, production and technological indicators of the enterprise may affect the accuracy of the results obtained. The models used mostly take into account general aspects of technological management, but do not sufficiently detail the specifics of individual industries or regions. Further research consists in improving the models taking into account regional and industry characteristics of enterprises, expanding databases and introducing innovative analysis methods. It is also advisable to integrate environmental and social indicators into the system of technological management assessments and to study its relationship with other aspects of economic security, which will allow adapting the models to the conditions of the modern economic environment and ensuring their relevance in the context of global challenges and risks. Therefore, for further development, it is advisable to create models that take into account the specifics of individual enterprises operating in different conditions, as well as to increase attention to the impact of technological management on ensuring the economic security of enterprises in the context of globalisation and market instability. One of the important areas is the integration of modern technologies, such as complex systems analytics, to increase the accuracy of forecasts and adapt strategies to changing economic conditions.

**Funding:** this study was conducted without external funding.
**Conflicts of interest:** the authors declare no conflict of interest.
**Use of artificial intelligence:** the authors confirm that they did not use artificial intelligence technologies during the creation of this work.

**REFERENCES**

1. Abbate, S., Centobelli, P., & Cerchione, R. (2023). The digital and sustainable transition of the agri-food sector. *Technological Forecasting and Social Change*, 187, 122222. https://doi.org/10.1016/j.techfore.2022.122222.

2. Balanovska, T. I., Gogulya, O. P., Troian, A. V., & Yazlyuk, B. O. (2020). Profitability analysis of digitalization of precision farming. *International Journal of Advanced Science and Technology*, 29(6s), 1030–1036. Retrieved from http://sersc.org/journals/index.php/IJAST/article/view/9165.

3. Cherep, A. V., Cherep, O. G., & Ogrenich, Yu. O. (2022). Improving the scientific and methodical approach to assessing the impact of factors on the use of the mechanism for forming a strategy for anti-crisis management of operational activities of industrial enterprises in crisis conditions. *Financial and Credit Activity Problems of Theory and Practice*, 1(42), 134–144. https://doi.org/10.55643/fcaptp.1.42.2022.3681.

4. Cherep, A. V., & Shvets, Yu. O. (2020). Development of an approach to assessing the influx of internal factors into the secondary mechanism of forming an anti-crisis management strategy for the operational activities of industrial enterprises. *Black Sea Economic Studies*, 50-2, 162–166. https://doi.org/10.32843/bses.50-66.

5. Corallo, A., De Giovanni, M., Latino, M. E., & Menegoli, M. (2024). Leveraging on technology and sustainability to innovate the supply chain: a proposal of agri-food value chain model. *Supply Chain Management: An International Journal*, 29(3), 661–683. https://doi.org/10.1108/SCM-12-2022-0484.

6. Di Vaio, A., Boccia, F., Landriani, L., & Palladino, R. (2020). Artificial intelligence in the agri-food system: rethinking sustainable business models in the COVID-19 scenario. *Sustainability*, 12(12), 4851. https://doi.org/10.3390/su12124851.

7. Furman, D., Shchokin, R., Kubitskyi, S., Chaplinskyi, V., Strochenko, N., & Dorosh, I. (2023). Motivation and incentives for employees of domestic enterprises. *Journal of Law and Sustainable Development*, 11(3), e815. https://doi.org/10.55908/sdgs.v11i3.815.

8. Gudz, O., Prokopenko, N., Korsakov, D., & Solovei, N. (2020). Insurance and innovative technologies of risks management of Ukrainian companies in the digital economy. *Studies of Applied Economics*, 38(4). https://doi.org/10.25115/eea.v38i4.3996.

9. Gutorov, O. I., & Gutorova, O. O. (2013). Theoretical and methodical basis of management efficiency estimation. *Bulletin of the KhNAU. Series: Economic Sciences*, 5, 38–47. Available at: http://nbuv.gov.ua/UJRN/Vkhnau_ekon_2013_5_8.

10. Hamidoğlu, A. (2024). A game-theoretical approach on the construction of a novel agri-food supply chain model supported by the government. *Expert Systems with*

*Applications*, 237(A), 121353. https://doi.org/10.1016/j.eswa.2023.121353.

11. Khodakivska, O., Kobets, S., Bachkir, I., Martynova, L., Klochan, V., Klochan, I., & Hnatenko, I. (2022). Sustainable development of regions: modeling the management of economic security of innovative entrepreneurship. *International Journal of Advanced and Applied Sciences*, 9(3), 31–38. https://doi.org/10.21833/ijaas.2022.03.004.

12. Kopishynska, O., Utkin, Y., Sliusar, I., Galych, O., Kovpak, S., Liashenko, V., & Barabolia, O. (2024). Comprehensive management of agroecosystem productivity on the platform of specialized farm management information systems. *Proceedings of World Multi-Conference on Systemics, Cybernetics and Informatics, WMSCI*. Available at: https://www.iiis.org/CDs2024/CD2024Summer/papers/SA421NY.pdf.

13. Krstić, M., Agnusdei, G. P., Miglietta, P. P., & Tadić, S. (2022). Logistics 4.0 toward circular economy in the agri-food sector. *Sustainable Futures*, 4, 100097. https://doi.org/10.1016/j.sftr.2022.100097.

14. Kushniruk, V., Kulinich, T., Roik, O., & Lushchyk, M. (2021). Sustainable development: strengthening of food security in EU countries. *Scientific Horizons*, 24(11), 85–91. https://doi.org/10.48077/scihor.24(11).2021.85-91.

15. Kyryliuk, I., Kyryliuk, Y., Proshchalykina, A., Zos-Kior, M., & Dovbush, V. (2021). Organisational and economic drivers for safety provision and quality upgrading of core livestock products in Ukraine. *Journal of Hygienic Engineering and Design*, 36, 49–66. Available at: https://keypublishing.org/jhed/wp-content/uploads/2021/11/4.-JHED-Volume-36-FQS-Abstract-Iryna-Kyryliuk.pdf.

16. Lezoche, M., Hernandez, J. E., del Mar Eva Alemany Díaz, M., Panetto, H., & Kacprzyk, J. (2020). Agri-food 4.0: a survey of the supply chains and technologies for the future agriculture. *Computers in Industry*, 117, 103187. https://doi.org/10.1016/j.compind.2020.103187.

17. Markina, I., Diachkov, D., Bodnarchuk, T., Paschenko, P., & Chernikova, N. (2022). Management of resource-saving and energy-saving technologies as an innovative direction of agri-food enterprise restructuring. *International Journal of Innovation and Technology Management*, 19(2), 2150047. https://doi.org/10.1142/s0219877021500474.

18. Markina, I., Somych, N., Taran-Lala, O., Varaksina, E., Potapiuk, I., & Vovk, M. (2022). Managerial Aspects of forming enterprises' competitive advantages: the case of agri-food sector. *Journal on Food System Dynamics*, 13(1), 56–68. ttps://doi.org/10.18461/ijfsd.v13i1.A5.

19. Miranda, B. V., Monteiro, G. F. A., & Rodrigues, V. P. (2021). Circular agri-food systems: a governance perspective for the analysis of sustainable agri-food value chains. *Technological Forecasting and Social Change*, 170, 120878. https://doi.org/10.1016/j.techfore.2021.120878.

20. Official website of the State Statistics Service of Ukraine (2024). *Agriculture of Ukraine for 2022*. Available at: https://www.ukrstat.gov.ua/druk/publicat/kat_u/2023/zb/09/S_gos_22.pdf.

21. Onegina, V., Kucher, L., Kucher, A., Krupin, V., Kłodziński, M., & Logos, V. (2025). Unlocking innovation capacity: strategies for micro-, small, and medium enterprises in Ukrainian agriculture. *Agriculture*, 15(1), 65. https://doi.org/10.3390/agriculture15010065.

22. Pilyavoz, T. M., & Glushchenko, L. D. (2018). Methodical approach to assessing the results of innovative development of an industrial enterprise. *Efektyvna ekonomika*, 6. Available at: http://www.economy.nayka.com.ua/pdf/6_2018/42.pdf.

23. Pyla, V. I., Arzyantseva, D. A., & Zakharkevich, N. P. (2016). Methodical approaches to assessing the effectiveness of enterprise management. *Economics, management, law: challenges and prospects*: collection of scientific articles. Discovery Publishing House Pvt. Ltd. Available at: https://www.researchgate.net/publication/327824254.

24. Pysarenko, V., Ponochovna, O., Bahorka, M., & Voronyansky, V. (2020). Data-centric formation of marketing logistic business model of vegetable market due to zonal specialization. In D. Ageyev, T. Radivilova, N. Kryvinska (Eds.), *Data-Centric Business and Applications. Lecture Notes on Data Engineering and Communications Technologies* (pp. 23–49), vol. 42. Springer, Cham. https://doi.org/10.1007/978-3-030-35649-1_2.

25. Rayets, M., Tkachuk, V., Buryk, M., Kubitskyi, S., & Zhaldak, H. (2023). The role of leadership in stimulating innovation and the creative potential of the team. *Economic Affairs*, 68(03), 1601–1610. https://doi.org/10.46852/0424-2513.3.2023.26.

26. Saurabh, S., & Dey, K. (2021). Blockchain technology adoption, architecture, and sustainable agri-food supply chains. *Journal of Cleaner Production*, 284, 124731. https://doi.org/10.1016/j.jclepro.2020.124731.

27. Tell, J., Hoveskog, M., Ulvenblad, P., Ulvenblad, P. O., Barth, H., & Ståhl, J. (2016). Business model innovation in the agri-food sector: a literature review. *British Food Journal*, 118(6), 1462–1476. https://doi.org/10.1108/BFJ-08-2015-0293.

28. Vashchenko, P. A., Zhukorskyi, O. M., Saenko, A. M., Khokhlov, A. M., Usenko, S. O., Kryhina, N. V., Sukhno, T. V., & Tsereniuk, O. M. (2023). The influence of feeding level on the growth of pigs depending on their genotype. *Regulatory Mechanisms in Biosystems*, 14(1), 112–117. https://doi.org/10.15421/022317.

29. Vovk, M. O. (2023). Technological management in the context of ensuring the economic security of agri-food enterprises (*PhD Thesis*). Poltava, Poltava State Agrarian University. Available at: https://dspace.pdau.edu.ua/server/api/core/bitstreams/62a1a299-9e9e-4bba-be45-dc919cf901d5/content.

30. Vovk, M., Lopushynska, O., & Oliynyk, A. (2022). Assessment of the level of production potential of agri-food enterprises. In D. Diachkov (Ed.), *Security Management of the XXI Century: National and Geopolitical Aspects* (pp. 224–228). Is. 4. Prague, Nemoros s.r.o. Available at: https://www.pdau.edu.ua/sites/default/files/academicdepartment/kafedra-menedzhmentu-im-ia-markinoyi/mono2022februarypislyaperevirky3compressed.pdf.

31. Yevseitseva, O., Liulchak, Z., Semenda, O., Järvis, M., & Ponomarenko, I. V. (2022). Digital-marketing as a modern tool for promotion of goods and services in social networks. *Financial and Credit Activity Problems of Theory and Practice*, 1(42), 361–370. https://er.knutd.edu.ua/handle/123456789/20584.

32. Yontar, E. (2023). Critical success factor analysis of blockchain technology in agri-food supply chain management: a circular economy perspective. *Journal of Environmental Management*, 330, 117173. https://doi.org/10.1016/j.jenvman.2022.117173.

33. Zhao, G., Liu, S., Lopez, C., Chen, H., Lu, H., Mangla, S. K., & Elgueta, S. (2020). Risk analysis of the agri-food supply chain: a multi-method approach. *International Journal of Production Research*, 58(16), 4851–4876. https://doi.org/10.1080/00207543.2020.1725684.

34. Zoria, O., Yasnolob, I., Galych, O., Cherchatyi, O., Tiutiunnyk, Y., Tiutiunnyk, S., Dugar, T., … & Mokiienko, T. (2022). Theoretical and methodological principles of investment support for innovation-oriented development of agrarian production. *Journal of Environmental Management & Tourism*, 13(3), 695–706. https://doi.org/10.14505/jemt.v13.3(59).10.

35. Zos-Kior, M., Kuksa, I., Samoilyk, I., & Storoška, M. (2017). Methodology for assessing globalisation development of countries. *Economic Annals-XXI*, 11–12, 4–8. https://doi.org/10.21003/ea.V168-01.

Citation:

*Стиль – ДСТУ:*

Vovk M., Zubro T., Omarov E., Kolomiiets B., Hnydiuk V. Modelling the efficiency of technological management of agricultural enterprises in economic security. *Agricultural and Resource Economics*. 2025. Vol. 11. No. 1. Pp. 262–287. https://doi.org/10.51599/are.2025.11.01.10.

*Style – APA:*

Vovk, M., Zubro, T., Omarov, E., Kolomiiets, B., & Hnydiuk, V. (2025). Modelling the efficiency of technological management of agricultural enterprises in economic security. *Agricultural and Resource Economics*, 11(1), 262–287. https://doi.org/10.51599/are.2025.11.01.10.