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THE IMPACT OF DIGITAL TECHNOLOGIES ON THE EFFICIENCY OF THE ACTIVITIES OF AGRICULTURAL SECTOR ENTERPRISES: A CASE STUDY OF UKRAINE

Mykola DZIAMULYCH[1*], Olha SHULHA[2], Petro KOSINSKYI[1*], Nataliia MOSTOVENKO[1], Oksana URBAN[1***], Myroslava KUPYRA[1**], Yurii LUCHECHKO[1*]**

[1]Lutsk National Technical University, *Department of Economics, **Department of Finance, Banking and Insurance, ***Department of International Economic Relations 75 Lvivska str., 43018, Lutsk, Ukraine. Emails: dziamulych.mykola@ukr.net, m.dziamulych@lntu.edu.ua, marmorcos@ukr.net, n.mostovenko@lutsk-ntu.com.ua, o.urban@lntu.edu.ua, m.kupyra@lutsk-ntu.com.ua, nashaorbita2018@gmail.com
[2]Borys Grinchenko Kyiv Metropolitan University, Department of Management, 13-B, Levka Lukianenka str., 04212, Kyiv, Ukraine. Email: o.shulha@kubg.edu.ua

Corresponding author: dziamulych.mykola@ukr.net

Abstract

The article examines the role of digital technologies in enhancing the efficiency of Ukraine's agricultural sector under current economic conditions. It is established that the digitalization of agricultural production serves as a critical factor in maintaining the sector's competitiveness. The dynamics of investments in digitalization and the level of digital skills among the rural population are analyzed, and their relationship with agricultural output is identified. Based on correlation-regression analysis, it is demonstrated that investments in the digitalization of business processes exert a significant positive effect on enterprise efficiency, while the development of digital competencies among the population produces a delayed impact. It is concluded that the combination of digital innovations with the development of human capital ensures the long-term growth of value added in the agricultural sector. The findings prove that the strategy of digital transformation in agriculture must be based on a balance between stimulating investment in advanced technologies and fostering digital skills among workers, since these factors generate conditions for innovative growth only through their interaction.

Key words**:** *agricultural sector digitalization, technology investments, digital skills of population, production efficiency, human capital*

INTRODUCTION

Currently, the situation in the agricultural sector of Ukraine can be characterized by two main trends - firstly, it is one of the most important components of the national economy, and secondly, the sector faces a technological gap associated with the slower pace of digital adoption in agricultural enterprises compared to industry and finance. Enterprises that have successfully integrated modern digital and information solutions demonstrate relatively higher operational efficiency. Overall, this indicates that the digital transformation of agriculture today is not an optional modernization, but a strategic factor for sustaining the competitiveness of the entire sector in global markets. This is explained by the fact that the profitability of agribusiness is largely determined by the efficiency of resource use, which increases significantly with the application of advanced digital technologies. Modern automated management systems and platforms for monitoring and controlling production processes impact not only enterprise productivity and operating costs but also financial resilience.

Practical evidence shows that the integration of digital technologies into business processes substantially increases the transparency of managerial decisions and ultimately leads to higher profitability and investment attractiveness. This underlines the relevance of assessing the efficiency of digital technology implementation in Ukraine's agricultural sector, which requires additional incentives to compete successfully in today's challenging global environment.

Contemporary research increasingly focuses on the role of digital technologies in transforming agricultural enterprises by

optimizing production processes. Significant contributions to this field have been made by scholars such as O. Agres [1], N. Antoniuk [2], I. Arakelova [3], M. Bezpartochnyi [4], I. Britchenko [5-9], A. Dibrova [10], S. Ionitescu [11], N. Khomiuk [12], V. Kostiuk [13], M. Kryshtanovych [14], N. Kunitsyna [15], M. Kuzheliev [16], I. Mazniev [17], T. Mirzoieva [19], A. Popescu [20-29], M. Rudenko [30], V. Sarioglo [31], T. Shmatkovska [32-38], R. Sodoma [39-40], D. Tanhua [42], A. Verzun [43], A. Zielińska [45] among others. Nevertheless, there remains a need to explore the specific factors influencing the efficiency of agricultural digitalization and enterprise management.

MATERIALS AND METHODS

The study is based on a comprehensive approach that combines both specialized and general scientific methods. In particular, the method of logical generalization was applied to interpret the obtained results and formulate conclusions. This allowed us to highlight the key role that digital technologies and human capital play in stimulating the economic growth of Ukraine's agricultural sector.

In addition, to determine the impact of selected factors on the production volume of agricultural enterprises, the study used correlation-regression analysis. To statistically verify the significance of the developed correlation-regression model, the coefficient of determination (R^2), Fisher's F-test, and Student's t-statistics for each variable were employed. The data were processed using the functionality of MS Excel software, which ensured calculation accuracy and enabled the visualization of the obtained results.

RESULTS AND DISCUSSIONS

Agriculture holds an essential position in the structure of Ukraine's national economy. Specifically, its share in total production accounts for approximately 10% of all output. It should be noted that the agricultural sector accounts for 55–59% of Ukraine's total export volume. As a result, agriculture is a fairly important component of the country's economic security [41]. At the same time, the importance of the agricultural sector is determined not only by its high share in the production structure, but also by its key role in shaping Ukraine's national food security. Ukraine is among the world's leading exporters of grains, oilseeds, and processed products, which makes agriculture a system-forming sector of external economic activity. The gross value added generated by agricultural enterprises has shown a steady upward trend despite market fluctuations (Fig. 1).

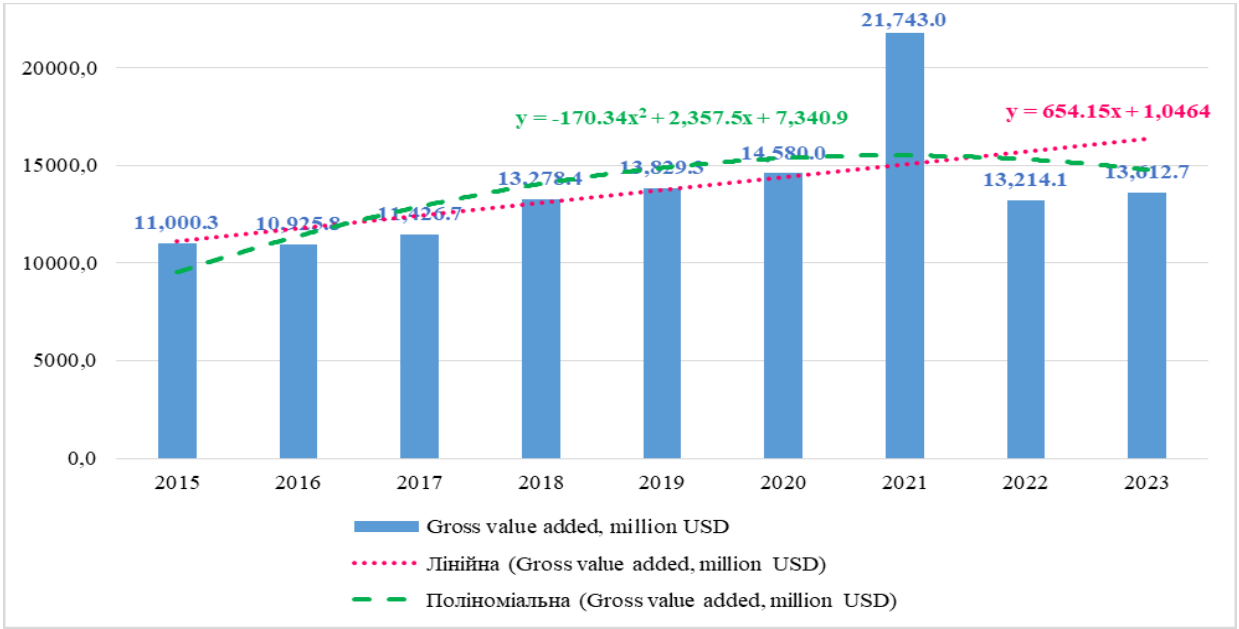

Fig. 1. Trend estimation of the gross value added of Ukraine's agricultural sector in 2015–2023
Source: compiled by the author based on [41].

As we can see, the linear trend shows that the GVA indicator of the agricultural sector of Ukraine in the analyzed period was characterized by growth. The absolute increase in this indicator amounted to 654.15 million USD. On the other hand, the analysis of the polynomial trend results shows that the actual annual change in gross value added reached 2,357.5 million USD, with an initial decline of 170.34 million USD.

It should also be emphasized that under conditions of economic destabilization, the agricultural sector acquires critical importance as an economic stabilizer, ensuring the inflow of foreign currency resources. Therefore, it can be argued that at present the agricultural sector serves as the foundation of Ukraine's economic resilience and long-term competitiveness.

Therefore, the key task for the national economy of Ukraine in the current conditions is to achieve high efficiency of agricultural producers. Digital and information technologies are of particular importance for this. Whereas 10–15 years ago their role was mainly limited to improving management systems and cost analysis, today digitalization encompasses precision farming systems, specialized ERP systems for agricultural producers, robotic technologies, and automation of agricultural machinery. However, it is worth noting that in practice, the implementation of these technologies requires agricultural producers to make significant additional investment costs. But, while the acquisition of advanced new machinery built on digitalization principles and equipped with network connectivity is classified as investment in fixed assets, expenditures on specialized information and digital technologies tailored to the needs of a particular producer require enterprises to mobilize additional financial resources. Therefore, enhancing the efficiency of digital solutions in the operations of agricultural companies necessitates corresponding investments (Fig. 2).

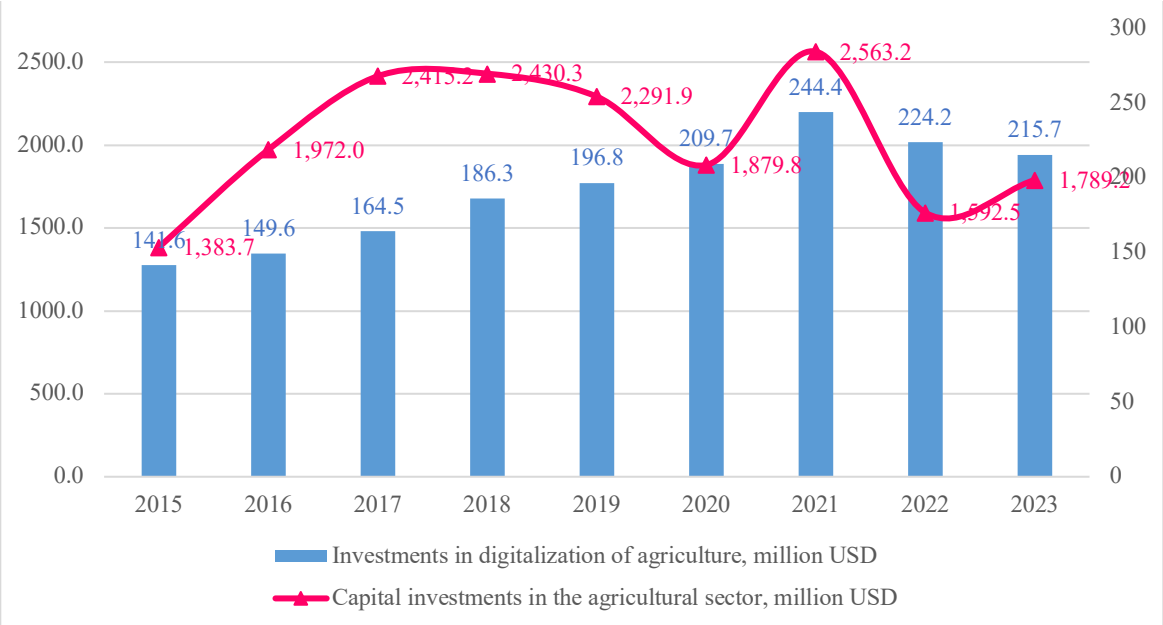

Fig. 2. Change in capital investments and investments in the digitalization of the agricultural sector of Ukraine in 2015–2023

Source: built by the author based on [41; 44].

From the diagram we see that the volume of capital investments in agriculture in Ukraine exhibited an upward trend until 2021, reaching a peak of more than USD 2.5 billion. However, in 2022–2023, a significant decline was observed, directly caused by overall economic destabilization and elevated risks for investors. At the same time, investments in digitalization, although relatively low in absolute terms, displayed a more stable dynamic. Their gradual growth indicates that even under crisis conditions enterprises sought to optimize costs

and improve production efficiency through the use of digital solutions. This trend can be explained by the comparatively lower costs of implementing digital technologies relative to large-scale infrastructure investments. In particular, while in 2015–2021 investments in digitalization averaged 9–10% of total agricultural sector investment, in 2022 this figure rose to 14.1%, and in 2023 it stood at 12.1%. As a result, these tendencies point to a gradual reconfiguration of agribusiness models towards more intensive adoption of technological innovations, which serves as a prerequisite for strengthening the sector's overall competitiveness.

Moreover, it should be emphasized that a fundamental condition for the successful implementation of digital technologies in agricultural enterprises is the availability of digital skills among the workforce to be employed in this sector. A shortage of workers capable of applying digital tools or interpreting data generated by relevant software applications may significantly reduce the overall efficiency of technological adoption. Considering the specific features of agriculture such as: soil management, crop cultivation, and logistics, workers' competencies play a decisive role in ensuring the effectiveness of innovations. As practice shows, in countries with a high level of digital literacy, investments in technology achieve faster returns and enterprises can reduce production costs. For Ukraine, this factor is particularly important, since a deficit of digital skills in rural areas may hinder the modernization of the agricultural sector. Thus, human capital with advanced digital competencies becomes a critical asset capable of transforming technologies into a competitive advantage for enterprises. Accordingly, it is essential to assess the level of basic and advanced digital skills among Ukraine's rural population to determine whether the labor force meets the needs of agricultural enterprises (Fig. 3).

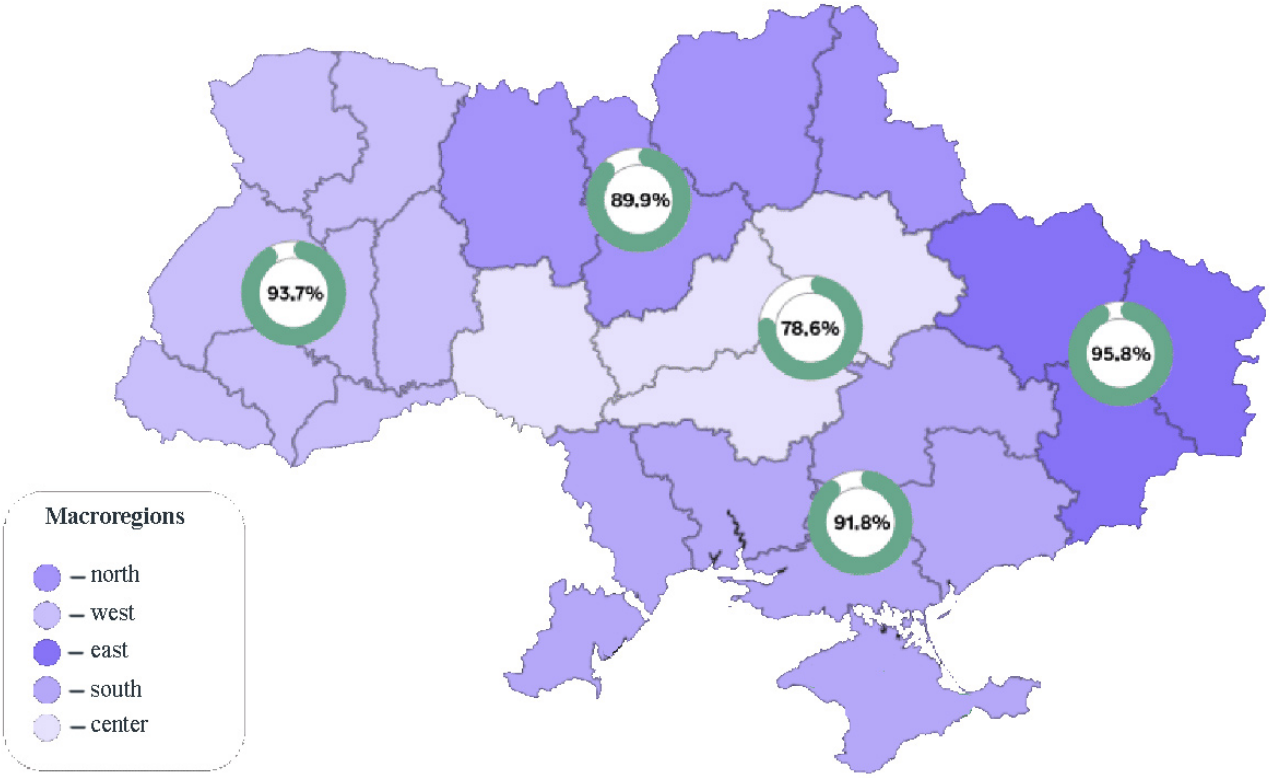

Fig. 3. Levels of basic and advanced digital skills among the rural population of Ukraine in 2024 by macro-regions
Source: [18].

Figure 3 shows that the highest levels of digital skills are recorded in the eastern regions of Ukraine – 95.8%, which indicates an active integration of digital technologies even in rural areas. High values are also characteristic of the western (93.7%) and southern (91.8%) regions, where a significant number of agricultural enterprises are concentrated. In contrast, the

northern macro-region demonstrates a somewhat lower level of digital literacy – 89.9%. Nevertheless, this level is still sufficiently high to ensure workers' readiness to adopt digital solutions. The lowest level of digital skills is observed in the central region – 78.6%, although even this figure is adequate for providing enterprises with personnel capable of using innovative products. Overall, these results indicate a substantial level of progress in the development of digital skills among Ukraine's rural population, which constitutes the foundation for the successful digitalization of the entire agricultural sector.

Since investments in production digitalization and the digital literacy of the population are, in our view, the key factors influencing the efficiency of agricultural enterprises in the context of digital technology adoption, it is appropriate to analyze their impact on overall productivity. It must be emphasized that enterprise performance will be affected not only by workers with basic but especially by those with advanced digital skills. To determine such influence, correlation analysis was applied, which makes it possible to identify the most significant relationships between agricultural output and the two selected factors. For empirical verification of this hypothesis, we developed and constructed a correlation-regression model. Annual statistical data for 2010–2023 were used regarding two independent variables relevant to the digitalization of agricultural enterprises in Ukraine and influencing production growth (Table 1).

Table 1. Dynamics of the indicators used for building the correlation-regression model, 2010–2023

Indicators	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Production volume, million USD	23,854.5	31,815.4	32,324.2	24,578.9	24,130.0	19,076.0	18,586.5	19,703.8	22,650.5	24,629.1	25,196.9	37,754.2	22,724.5	21,742.8
Investments in digitalization of agriculture, million USD	126.2	145.4	154.5	154.6	150.6	141.6	149.6	164.5	186.3	196.8	219.7	274.4	224.2	215.7
Share of rural population with advanced digital skills, %	4.1*	5.7*	7.2*	11.8*	19.4*	29.1*	32.8*	38.7*	42.3*	47	49.6	52.2	56.7	59.6

*the indicator of the level of digital skills for the period 2010–2018 was determined based on expert assessments of the Ministry of Digital Information of Ukraine.
Source: [18; 41; 44].

Table 2 presents the key parameters of the regression model that describes the influence of selected factors on the volume of agricultural production.

Table 2. Parameters of the developed correlation-regression model for determining the impact of selected factors on the volume of agricultural production (y)

Factor	Coefficient (B)	Standard error	t-statistic
Production volume, million USD (y)	293.231	2870.087	0.102
Investments in digitalization of agriculture, million USD (x1)	214.458	22.032	9.734
Share of rural population with advanced digital skills, % (x2)	-421.664	46.596	-9.049

Source: own research.

The correlation-regression model equation obtained as a result of the analysis describes the dependence of the production volume of agricultural enterprises on two key factors of digitalization:

$$y = 293.23 + 214.46x_1 - 421.66x_2$$

The obtained correlation-regression model indicates that the most significant factor in the growth of agricultural production is investment in digitalization. In particular, an increase of this indicator by 1 million USD leads, on average, to a rise in production volume of 214.5 million USD. Accordingly, this confirms the substantial effect of implementing digital technologies, the result of which is an increase in production efficiency.

By contrast, the coefficient for the share of the rural population with digital skills has a negative value (–421.7), which may reflect the ambiguous role of this factor. Most likely, the growth of digital literacy among the population alone cannot ensure a rapid increase in production volumes and requires enterprises to

make prior investments in the digitalization of their business processes.

The developed model confirms the hypothesis of the key importance of investments in digitalization for agriculture. However, there is also an objective need to ensure the proper balance between the level of human capital development and technological modernization of the industry. At the same time, it is absolutely clear that without synchronization of these factors, achieving the proper level of digitalization efficiency will be problematic.

To visualize the calculations, a comparison of actual and predicted production volumes was made using the constructed model (Fig. 4).

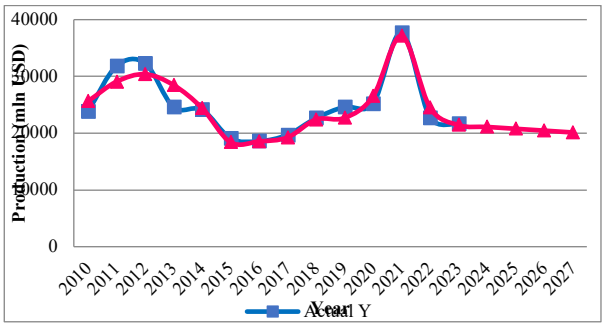

Fig. 4. Actual and predicted values of agricultural production in Ukraine according to the developed regression model

Source: own research.

The figure shows that the model adequately reflects the dynamics of Ukraine's agricultural production during 2015–2023. The lines of actual and predicted values are nearly parallel, which indicates a high level of consistency between the empirical data and the calculated results of the model. The convergence of these curves is particularly evident in periods of production growth after 2016 and in the decline phase of 2022–2023. Thus, the constructed regression model approximates the real dynamics well and accounts for the key influencing factors. The high coefficient of determination (R^2 = 0.899) confirms its reliability.

We also present the summary results of the correlation-regression analysis of the relationship between production volume and the selected factors. Specifically, the main coefficients of the developed correlation-regression model indicate the following:

Coefficient of determination (R^2 = 0.899) – the model explains about 90% of the variation in agricultural production, which demonstrates its high adequacy.

Adjusted R^2 (0.881) confirms the high accuracy of the model even when accounting for the number of included factors.

F-statistic: 49.04 ($p < 0.00001$) – the model as a whole is statistically significant.

Student's t-statistics:

- for x_1 (investments in digitalization): $t = 9.73$, $p < 0.001$ – the variable is statistically significant and has a substantial positive impact;
- for x_2 (digital skills of the population): $t = -9.05$, $p < 0.001$ – this variable is also statistically significant but exerts a negative effect in the short term.

Therefore, it can be argued that the developed model is reliable and demonstrates that both factors have a significant impact on the volume of agricultural production, although their effects differ in direction.

In addition, we proceed with the assessment of the correlation matrix (Table 3).

Table 3. Matrix of mutual correlation of factor and outcome variables

Indicators	Production volume (y)	Investments in digitalization (x_1)	Rural population with advanced digital skills (x_2)
Production volume (y)	1	X	X
Investments in digitalization (x_1)	0,385201	1	X
Rural population with advanced digital skills (x_2)	-0,174572	0.823365	1

Source: own research.

As shown by the calculations, the strongest correlation with the volume of agricultural production is demonstrated by investments in digitalization (0.385), whereas the correlation with the share of the rural population possessing digital skills is weak and negative (–0.175). This indicates that the short-term effect of digital competencies has not yet translated into an increase in production volumes. At the same time, investments in digital technological solutions directly enhance the performance of agricultural enterprises. Furthermore, the high level of interdependence

between the two factors (0.823) points to a structural relationship: investments in digitalization stimulate the spread of digital skills, but a certain period is required before the corresponding effect materializes.

Overall, the conducted correlation-regression analysis empirically confirmed the hypothesis regarding the significant impact of investments in digital technologies on the development of Ukraine's agricultural sector. The most statistically significant factor proved to be investment ($t = 9.73$, $p < 0.001$). In contrast, the negative regression coefficient for digital skills of the population ($t = –9.05$, $p < 0.001$) suggests that the growth of competencies does not immediately translate into positive economic outcomes. The reliability of the model is confirmed by the high coefficient of determination ($R^2 = 0.899$) and the statistical significance according to Fisher's criterion ($F = 49.04$, $p < 0.00001$). This indicates the suitability of the model for forecasting the dynamics of agricultural production.

The results obtained show that to ensure a high level of efficiency in Ukrainian agriculture, it is necessary to encourage agricultural enterprises to constantly increase investments in digital technologies. In addition, such investments should be combined with parallel human capital development to ensure their maximum effectiveness in the long term.

CONCLUSIONS

Therefore, it can be argued that stimulating investments in the digitalization of Ukrainian agriculture is currently a key indicator of its competitiveness. The results of the correlation-regression analysis confirm the key role of investments in digital technologies. Their growth has a statistically significant positive impact on agricultural production volumes, reflecting the tangible benefits of implementing technological innovations. At the same time, it should be noted that the impact of the population's digital skills on production volumes proved to be more complex – In the short term, their increase is accompanied by a negative effect. In our view, this is explained by the necessity of upfront expenditures for improving business processes and adjusting production systems according to new technological principles. However, as practice demonstrates, the development of digital competencies creates the foundation for the long-term return on investments in digitalization and for enhancing the efficiency of resource utilization in enterprises.

The developed model proves that the effective advancement of technical innovations and human capital is a necessary prerequisite for the successful digital transformation of Ukraine's entire agricultural sector. The digital development strategy must therefore focus on systematic investments not only in technologies but also in the upskilling of the rural population to implement these solutions directly in production. Only the combination of these factors generates the desired effect, ensuring cost reduction and the formation of long-term investment attractiveness for Ukrainian agricultural enterprises. Accordingly, these principles can serve as the basis for the strategic planning of the digital transformation of Ukraine's agricultural sector, provided that both economic and social dimensions of this strategy are taken into account.

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