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DIGITAL TECHNOLOGY MANAGEMENT AND RESOURCE EFFICIENCY IN AGRICULTURAL PRODUCTION

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Introduction. The active adoption of digital tools is crucial for improving agricultural efficiency, which is fundamental to ensuring food security. The digitalisation of agricultural production is a key component of the measures for transitioning to a digital economy.

Aim and tasks. This study aims to assess the relationship between the net profit of agricultural enterprises and the number of digital products used. It also seeks to identify the factors influencing the efficiency of agricultural production.

Results. This study examines at several key factors of agricultural production. First, it considers at the share of the labour force involved in agricultural production, which has declined by 17.2% globally, 7% in the EU, and 5.2% in Ukraine. Secondly, it analyses changes in the number of workers required to produce 1% of value added from 1991 to 2023, showing a decline of 3% globally, 1.5% in the EU and an increase of 0.5% in Ukraine. Thirdly, the study assesses the level of digital skills among workers in the agricultural sector. In the EU, this level did not exceed 0.5% from 2016 to 2024, while Ukraine data is unavailable. Finally, the study includes case studies of two Ukrainian companies engaged in developing and implementing digital tools for agricultural production. The findings regarding the dependence of net profit and the number of digital instruments used revealed relatively high correlation coefficients: 0.776 for a group of 41 AGRIChain clients and 0.902 for a group of 34 Kernel Digital clients. The resulting models of net profit dependence on the number of digital instruments used (with slope coefficients of 365.9 for AGRIChain and 13.13 for Kernel Digital) indicate the potential for further refinement.

Conclusions. The establishment of a digital support system for agricultural production involves significant changes in employee competencies, a decrease in the total number of employees, and a reduction in the share of employees involved in agricultural production. Ukraine is characterised by an increase in the number of workers employed in agricultural production per 1% of added value, which is explained by structural changes in the industry. This study proposes adding metrics to statistical reporting to capture the number of digital technologies used in the production process and the number of employees skilled in using these technologies.

Keywords: digitalisation, agriculture, production efficiency, digital literacy, food security.

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1. Introduction.

The formation of the digital economy has varying degrees of impact on different economic sectors, leading to imbalances in their development (Singh et al., 2025). Given that agro-industrial production underpins food security, the implementation of qualitatively new operations in agriculture requires tools adapted to interact with other components of the production process, as well as systems to monitor and mitigate the environmental impact of agro-industrial activities (Fernandez-Mena et al., 2016).

The development of digital tools in various areas of agricultural production necessitates the formation of a certain level of digital skills among agricultural workers and the presence of specialists who professionally engage in the creation, testing, adaptation, and subsequent modernisation of digital tools for agriculture (MacPherson et al., 2022). As the level of digitalisation of agricultural production increases, it leads to changes in the workforce structure involved in the production processes. Furthermore, precise mechanisms are needed to forecast the demand for specialists with expertise in information and communication technologies (ICT).

Creating a robust information base for analysing past technological operations in the agricultural sector is one of the main conditions for developing digital tools that support decision-making to improve resource-use efficiency. Even though commercial companies are independently developing and implementing digital tools for agricultural production, challenges may arise in exchanging information.

Overall, the digitalisation of agricultural production requires significant improvement, both in enhancing digital tools and improving coordination between technical tools and systems designed to analyse data and generate decision scenarios. Since the efficiency of agricultural production is determined by many factors, including natural ones, it is necessary to include historical weather data and short- and long-term weather forecasts in the analytical components of digital tools supporting agricultural production.

This study aims to identify the relationship between agricultural production efficiency and the level of agricultural digitalisation. In this regard, the following research questions (RQ) were formulated:

RQ 1. How do digital tools affect the development of various components of agricultural production?

RQ 2. Is providing specialists proficient in information and communication technologies sufficient for agricultural digitalisation?

RQ 3. How does the use of digital technologies affect the net profit of agricultural producers?

2. Literature Review.

Digitalisation is actively studied by practitioners developing and implementing digital tools and products, as well as by specialists across various economic sectors where these technologies are applied. To obtain comprehensive and stable information on the nature and degree of intensity of the impact of the introduction of digital products into agricultural activities, a systematic analysis of studies by specialists in the field of agricultural production was conducted.

Many studies have addressed the challenges of effective interaction among digital product users in the agricultural sector. Ehlers et al. (2021) examined the evolution of agricultural policy in the era of digitalisation, noting that policy tools for managing the agricultural sector require significant adjustments due to the need for regulatory frameworks that support the implementation of digital technologies in agriculture.

The development of agricultural technologies is closely linked to the achievement of sustainable development goals (SDGs). This objective must be considered when designing and implementing digital tools in agricultural production, which will affect the formation of future agricultural systems (MacPherson et al., 2022). Guerrero-Ocampo and Díaz-Puente (2023) emphasise the special importance of social networks in creating and maintaining professional communications in the agricultural sector.

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The study explored the potential of social networks to support innovative initiatives in the agricultural sector. Social networks can facilitate professional dialogue during innovation implementation, allowing for timely adjustments that are especially valuable for fostering innovative diversity (Guerrero-Ocampo & Díaz-Puente, 2023; Di Virgilio et al., 2023).

Șerbănel (2021) considered the European agricultural sector an open system with a wide range of open trends in digitalisation. Gabriel and Gandorfer (2023) consider digital technologies as practical accounting tools for planning expenses and inventory of means of production at the scale of individual regions.

Salinas-Ramos et al. (2021) investigate the digitalisation features of agri-food cooperatives in different regions of Europe and study the influence of various factors on the implementation processes of information and communication technologies in these business entities. This group of researchers considers the possibilities of transforming the existing digital tools used in agricultural production, both for complex use and for analysing the efficiency of agricultural production in earlier periods.

The possibilities of adapting and using digital tools in agriculture in areas with high agricultural fragmentation draw attention to the discrepancy between the market for digital products and the needs of farmers, whose activities are fragmented and require processing significant amounts of information (Kramarz & Runowski, 2025).

Garske et al. (2021) considered using artificial intelligence in agriculture to model climate change and species characteristics of biodiversity in individual areas for more systematic adaptation of agricultural producers to changes in future periods.

Tey and Brindal (2022) conducted a meta-analysis of the factors contributing to the implementation of precision agriculture. This will provide more reliable information on the processes of land cultivation, resource allocation, fertilisers, and plant protection products applied to obtain the final agricultural products. The same aspects were considered by Lacoste et al. (2025), who presented the results of experiments focused on farmers.

The results of the experiments were on the mechanisms of using digital tools to scale up transformations in agricultural production. The range of applications of digital tools in agriculture is extensive, allowing the collection of large volumes of initial data necessary for obtaining a more extensive basis for decision-making in managing agricultural processes in the following periods.

This information can concern both agro-technological measures, as shown by Weckesser et al. (2022) in the study of digital tools for nitrogen management in crops, and financial measures, the results of which are presented by Gajdosikova and Michalek (2025), who offer a comparison of the effectiveness of artificial neural networks and decision trees as the main models of artificial intelligence used to predict bankruptcy in agriculture.

However, implementing digital technologies requires an integrated approach to solve several issues. One of the challenges in implementing digital tools in agriculture is the low digital literacy of farmers, as noted by Fróna and Szenderák (2024). Adapting workers in the agricultural sector to modern digital components is key because the level of development of digital tools in different sectors of economic activity is different, which leads to disproportions in the digitalisation of various areas of economic activity.

The problem of digitalisation in agriculture has been comprehensively and systematically studied. However, several issues require thorough investigation. The relationship between digital tools, resource accounting, and quality control systems in agricultural production has not been fully explored, which complicates analysing the effectiveness of agricultural activities and planning expenses and profits for future periods. This makes agricultural production more predictable in terms of planning resource costs and development opportunities. The issue of labour force readiness to actively ensure the functioning of digital tools in agricultural production and the need to improve workers' digital literacy requires additional research.

Further research should pay special attention to how profit depends on the level of digitalisation in agricultural production.

3. Methodology.

3.1. Description of the Initial Data.

Initial data collection focused on obtaining the most objective information on gross value added, the number of individuals involved in agricultural production, and total agricultural employment per 1% of added value. The most extended possible study periods were selected, as these indicators reflect quantitative and qualitative shifts in the agro-industrial sector. For comparative purposes, global data, figures from the European Union (a key strategic partner of Ukraine), and Ukrainian data were used. This approach enables trend analysis and the formulation of recommendations for improving the situation in Ukraine.

When collecting information on available digitalisation tools in agricultural production, a generalisation method was used, this made it possible to structure and synthesise information on the current state of affairs in the industry of digital products developed and used in agricultural production. Since the use of digital products in agriculture is impossible without the participation of workers with sufficiently high digital skills, it is necessary to have information on the number of such workers to study their ability to use digital tools actively. This information is provided only for European Union countries from 2015 to 2024; such statistics are not maintained in Ukraine.

The analysis of net profit data from 2011 to 2024 was used to investigate the economic drivers behind Astarta-Kyiv's decision to establish a subsidiary focused on developing and implementing agricultural software solutions. To obtain information on the impact of the efficiency of introducing digital tools into the agro-industrial complex of Ukraine, two of the largest manufacturers of digital products for agriculture were selected: AGRIChain and Kernel Digital, as well as information on the number of digital products supplied to the largest customers.

For the companies' clients, data on net profit for the period of use of digital products of the manufacturers studied in this study were selected.

3.2. Empirical Study Description.

When analysing the indicators of the percentage of added value from GDP, employment in the agricultural sector, and the number of people employed in the agricultural sector per 1% of added value, absolute indicators were considered which were studied depending on the time indicators. In addition, the percentage of agricultural workers with information and communication skills in European Union countries was studied in terms of time dynamics.

The dynamics of the net profit of enterprises in the agro-industrial sector were considered for the Astarta-Kyiv Company from 2011 to 2024 and for companies that are clients of the main manufacturers of digital tools for agricultural producers for the period of use of these digital tools.

The impact of digital tool usage on enterprise net profit was assessed by calculating the correlation coefficient (r) between the number of digital tools (A) and the net profit (Pr) of agro-food enterprises, as defined by formula (1).

$$r=\frac{n\sum_{i=1}^{n}A_iPr_i-\sum_{i=1}^{n}A_i\sum_{i=1}^{n}Pr_i}{\sqrt{\left(n\sum_{i=1}^{n}A_i^2-\left(\sum_{i=1}^{n}A_i\right)^2\right)\left(\sum_{i=1}^{n}Pr_i^2-\left(\sum_{i=1}^{n}Pr_i\right)^2\right)}} \quad (1)$$

The presence of a relationship between variables was determined using standard control indicators of the correlation coefficient: at a value of +1, both variables increase proportionally, while at −1, one variable increases and the other decreases). A value of 0 indicates no linear relationship, meaning that changes in one variable do not predict changes in the other. The nature of the observed relationship was interpreted based on the standard value to which the calculated coefficients were closest.

A one-factor variance analysis was conducted with a significance level of 0.05 to test the significance of the obtained dependence.

When conducting the study, the p-value represents the probability that the observed differences between the mean values of the groups (or samples) could have arisen by chance if there were no fundamental differences between the groups.

If the p-value was less than the selected significance level (0.05), the differences between the means were statistically significant. As the number of digital products developed and implemented in agricultural production continues to grow, it is appropriate to forecast the average net profit of agricultural producers as a function of the number of digital products used.

Given the independent variable A and the dependent variable $P\,r$, the following system of equations is used to determine the coefficients of their linear relationship (formula 2):

$$\begin{cases} a\sum_{i=1}^{n} A_i^2 + b\sum_{i=1}^{n} A_i = \sum_{i=1}^{n} A_i Pr_i \\ a\sum_{i=1}^{n} A_i + nb = \sum_{i=1}^{n} Pr_i \end{cases} \quad (2)$$

With a mathematical model describing the dependence of agricultural producers' profits on the number of digital tools used, companies engaged in developing and implementing such tools can more systematically approach the process of identifying additional opportunities to increase digitalisation in agriculture.

4. Results.

Agricultural production is distinct among industries, as its quality significantly influences food security and overall standard of living. When analysing agriculture as a component of the economic framework, focusing on the growth rate of the gross added value generated within the agricultural sector is crucial. This metric serves as a valuable indicator of economic development intensity.

Generally, the more advanced a country or group of countries is in industrial and technological progress, the lower the share of gross value added from agriculture, forestry, and fisheries in total GDP In most developed countries, this share is declining due to more efficient production, the growing value of information, and increased productivity across industries. Figure 1 presents the value-added (% of GDP) indicators in agriculture, forestry, and fishing for Ukraine, the European Union, and the world. The global growth rate of gross value added is stable, with a slight decrease of 11% over the observation period from 1991 to 2023 (4.59% in 1991 versus 4.1% in 2023), with a minimum of 3.16% recorded in 2006 and a maximum of 4.59% in 1991.

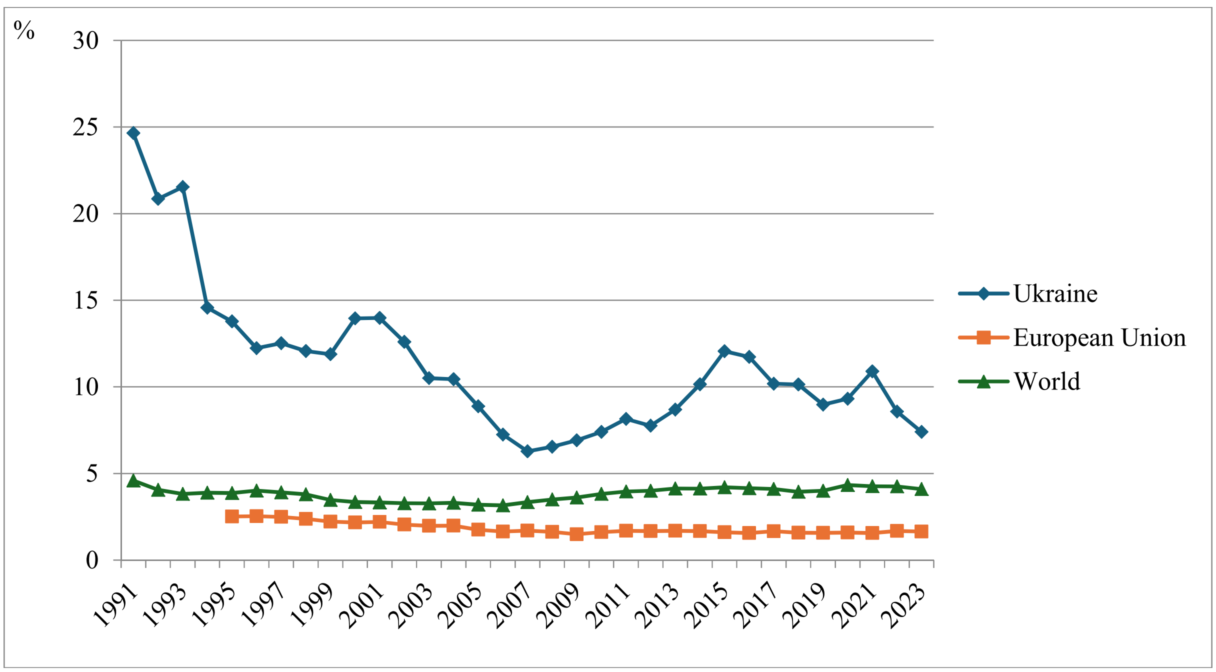

Fig. 1. Value Added in Agriculture, Forestry and Fishing, (% of GDP).
Source: based on the World Bank Open Data (2024).

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Minor gaps indicate a relatively stable world concerning value added in agriculture. The European Union is characterised by a very low percentage of gross value added from GDP, which averaged 1.85% from 1995 to 2023, with the maximum value recorded in 1996 at 2.53% and the minimum of 1.49% in 2009. The general trend of this indicator for the EU is downward, indicating a high level of industrial and information components in the formation of value-added. Significant value-added indicators formed in agriculture, forestry, and fisheries are evident in Ukraine as a share of the gross domestic product. From 1991 to 2023, this indicator reached a maximum value of 24.65% in 1991 and a minimum of 6.28% in 2007. This indicator decreased and increased during the observation period, indicating instability in this sector and other economic branches. Relatively high indicators of added value as a percentage of gross domestic product, compared to the European Union, a path Ukraine has chosen, indicate the need for radical changes in the structure of the economy. The level of employment in agriculture, based on the total working population, characterises the composition of the technical means used to produce agricultural products. Figure 2 shows the level of employment in agriculture in Ukraine, the European Union, and the world.

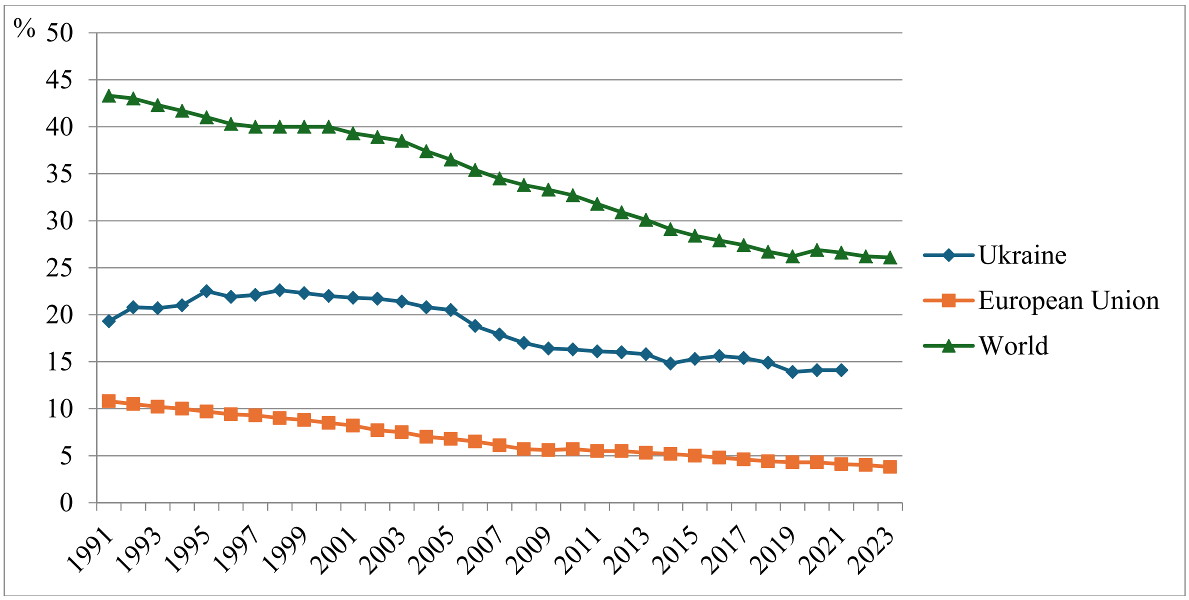

Fig. 2. Employment in Agriculture, % of Total Employment (Modelled ILO Estimate).
Source: based on the World Bank Open Data (2024).

The global share of employment in agricultural production declined significantly over the observation period, from 43.3% in 1991 to 26.1% in 2023. In Ukraine, agricultural employment increased and decreased during the observation period. The maximum employment in agriculture in Ukraine was observed in 1998, reaching 22.6% of the total employed, and the minimum in 2019, when 13.9% of the total employed in Ukraine worked in the agriculture sector. The European Union has experienced a steady decline in agricultural employment, from 10.8% in 1991 to 3.8% in 2023. Figure 3 shows the ratio of the percentage of people employed in agriculture to the percentage of gross value-added to the gross domestic product. Global indicators show a relatively high percentage of labour spent in agriculture, forestry, and fisheries to obtain added value, which is caused by significant gaps in the level of labour costs in different countries. For the European Union, this indicator steadily declined. Over the observation period from 1995 to 2023, it decreased from 4% to 2.3% owing to an increase in the level of equipment with technical means in all industries included in this indicator, including forestry and fishery. Ukraine had the lowest indicators (0.8% in 1991 to 2.9% in 2007) due to large sown areas with a relatively small share of forestry and fishery.

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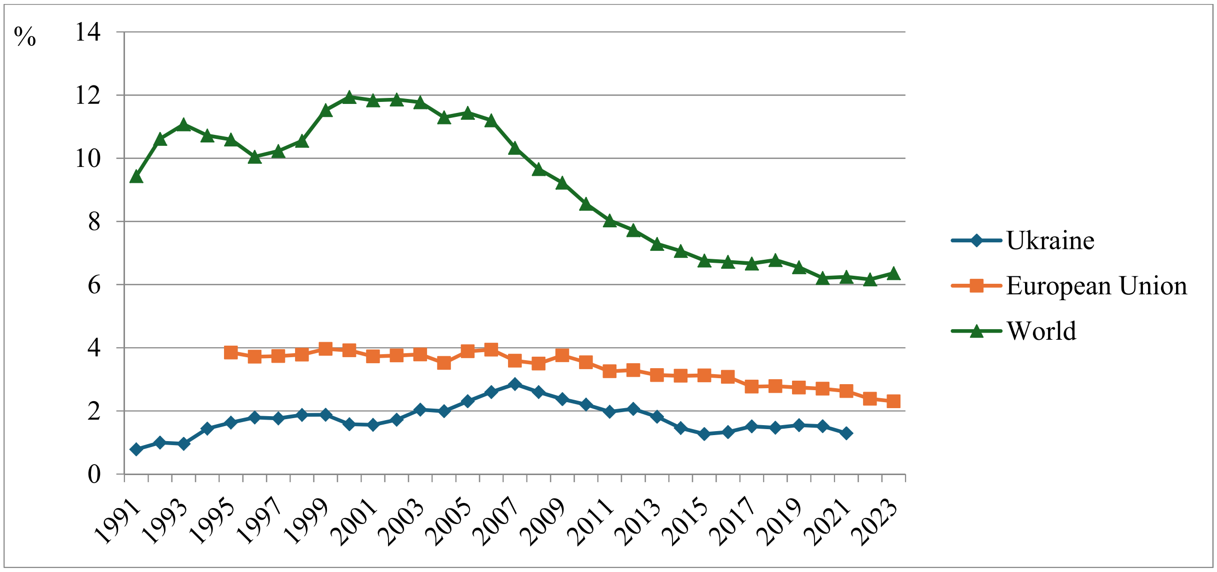

Fig. 3. Employment Decline (%) per 1% Decrease in Value Added (% of GDP) in Agriculture, Forestry and Fishing.

Source: based on the World Bank Open Data (2024).

Given global and regional trends toward reducing manual labour, it is necessary to improve familiarity with digital tools in agricultural production and ensure adequate personnel support for their effective use. Agricultural production consists of processes that are only partially amenable to strict algorithmisation due to the need for constant adjustment based on various factors, most of which are natural—such as weather conditions, plant and animal diseases, and the response of living organisms to human interventions like fertiliser application, drug use, agricultural techniques, and other factors that can significantly affect the final efficiency of agriculture.

Various digital tools, including technological equipment and artificial intelligence, are employed to develop optimal agricultural solutions. Key agricultural digital tools include precision farming systems, satellite monitoring, management software, the Internet of Things, mobile applications, big data, blockchain technologies, robots, and specialised machinery.

Precision farming systems enable precise equipment control, helping avoid gaps or double processing during sowing, planting, fertiliser application, and other operations.

Based on the results obtained from these systems, agrochemical maps were compiled by introducing various soil components. These maps can be used to determine the amount of land rent of the second kind as well as yield maps, which are compiled by recording the yield using precision farming systems in the process of mechanical harvesting or by entering the relevant data by specialists during manual harvesting, for example, for some varieties of berries, fruits, melons, and other crops. The data obtained can be used to assess soil fertility and to plan agrotechnical measures for subsequent periods. In addition, data obtained using precision farming systems can be used as a differentiated approach to land cultivation. This is especially important when taking soil samples to determine the composition and amount of additional agrotechnical means.

Satellite monitoring is used to identify problematic areas that may be sources of reduced agricultural production efficiency, such as pests and weeds. Local climate change may occur due to imbalances in forestry; for example, chaotic destruction of forest belts can cause drought due to increased wind speed, which leads to accelerated evaporation of moisture obtained by crops by natural and agricultural means.

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Satellite monitoring allows for the identification of drought areas and coordination of local actions by authorities who must take measures against illegal logging of forest plantations and forest belts. Spectral analysis data of crops obtained during satellite monitoring allows for the determination of the normalised vegetation index, which is an identifier of the state of plants during the agricultural season. Spectral analysis data obtained during satellite monitoring can be used to form directions for more in-depth research as they reflect the current state of crops without determining cause-and-effect relationships. However, they can also be used to obtain precise coordinates of the problem areas. Satellite monitoring can also be used to create maps for the targeted application of fertilisers and plant protection products.

The software used to manage agricultural production processes aims to generate primary information on crop volumes, record seed sources and current treatments, track the origins of preparations used during treatments, and provide quantitative and qualitative indicators of the harvested crop. The primary data obtained enable financial control to optimise costs, record income, and account for the depreciation of technical equipment. These data are also fundamental for planning crop rotations, determining the volumes and timing of agrotechnical measures, and generating the necessary logistics flows. Additionally, agricultural production management software provides quick access to field histories and other monitoring data.

The Internet of Things (IoT), as in many other sectors of the economy, is used in the production of agricultural goods. The main functions of the IoT in agricultural technology include monitoring, automation, and remote control. Monitoring is often employed to create a database of microclimate indicators, that is, the systematic recording of temperature, air and soil humidity, light intensity, and other variables. The Internet of Things is used to manage drip and fan irrigation systems, regulate climate conditions in greenhouses with the ability to control all climate systems remotely and feed livestock with the option to provide individual diets for breeding stock.

The availability of remote control capabilities signifies the emergence of more efficient methods for utilising labour resources in agricultural production. Multiple mobile applications have been developed, the functionality of which can be broadly divided into two main categories: informative and applied. Informative mobile applications allow farmers to receive up-to-date information on agronomy, such as details on plant varieties, calculation methods, and technologies for applying fertilisers, plant protection products, and weather forecasts tailored to specific locations. Mobile applications enable interaction with smart systems used in agriculture, planning their use, and organising other work and expenses associated with primary and auxiliary production means. With the help of mobile applications, it is possible to calculate the application rates of fertilisers and plant protection products, which farmers can use when making decisions independently or based on the results of laboratory analyses.

The operation of various programs and applications for digital support in agricultural production generates large volumes of data, the analysis of which forms the basis for making forecasts. High-quality data processing makes it possible to adjust agricultural production locally and globally, which is fundamental to ensuring global food security.

Large datasets obtained through private and large-scale monitoring can be used to revise work schedules and select crop varieties best suited to the climatic conditions of specific regions over short or medium-term periods. By analysing data on the physiological and phenological characteristics of animals and plants, researchers have gained valuable insights to guide targeted studies and selective breeding programs. As the spatial and temporal scope of the input data expands, the accuracy of predictionting of resource requirements improves significantly. This more comprehensive dataset allows for more efficient resource allocation, optimises usage, and reduces unnecessary expenses.

This approach improves forecasting accuracy and contributes to sustainable planning and cost management by minimising misallocations and superfluous overheads.

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Consumers are increasingly concerned about food quality, driving interest in producing produce, especially organic products, which utilise supply chain-tracking systems. The application of various digital tools enables tracing a product's history from the initial stage, such as seed selection, to the point of sale. This enhances consumer and partner trust and is an effective tool for combating counterfeiting and ensuring transparency in quality control and product authenticity. The development of robotic devices facilitates autonomous operations such as sowing, harvesting, sorting, and processing, reducing reliance on manual labour. Automated systems boost productivity in fields and farms and enable the collection of accurate and objective data essential for further analysis and decision-making.

To ensure the effective use of digital tools in agriculture, it is essential to provide the industry with specialists skilled in information and communication technology (ICT). Currently, not all countries statistically track the number of ICT-skilled specialists across different economic sectors or the level of digital skills among professionals in traditional occupations.

This gap partly exists due to the general trend of rising digital literacy. However, many specialised production processes involving intelligent systems require significantly higher digital skills than the commonly accepted baseline. Figure 4 presents the share of agricultural specialists with ICT skills as a proportion of all such specialists in European Union countries from 2015 to 2024.

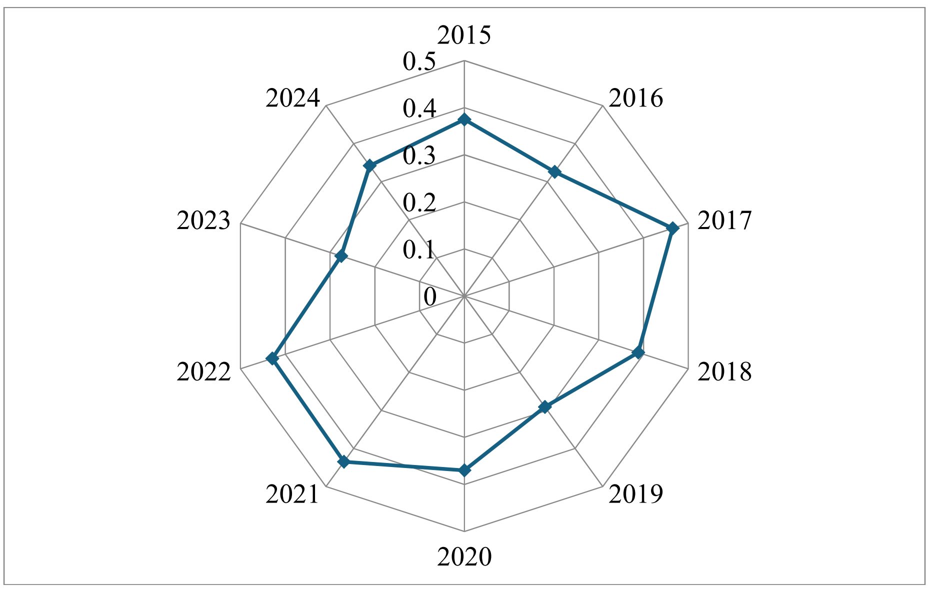

Fig. 4. ICT Specialists in the EU Agricultural Sector, (%).
Source: based on the Eurostat Open Data (2025).

The demand for digital tools in agricultural production is possible only if there is interest from agricultural producers. A striking example in the Ukrainian market is the creation of a subsidiary by the agro-industrial company Astarta-Kyiv, which is engaged in the development and implementation of digital tools in agricultural production. Among the prerequisites for this process were the company's unstable financial results (Figure 5).

The company's management decided to transition to digital tools, and the first product was developed in 2017. This enabled the implementation of digital solutions at its production facilities and provided clients with a comprehensive support package. A study of 41 companies using AGRIChain products found that specialists skilled in information and communication technologies make up no more than 0.322% of the workforce (Figure 6).

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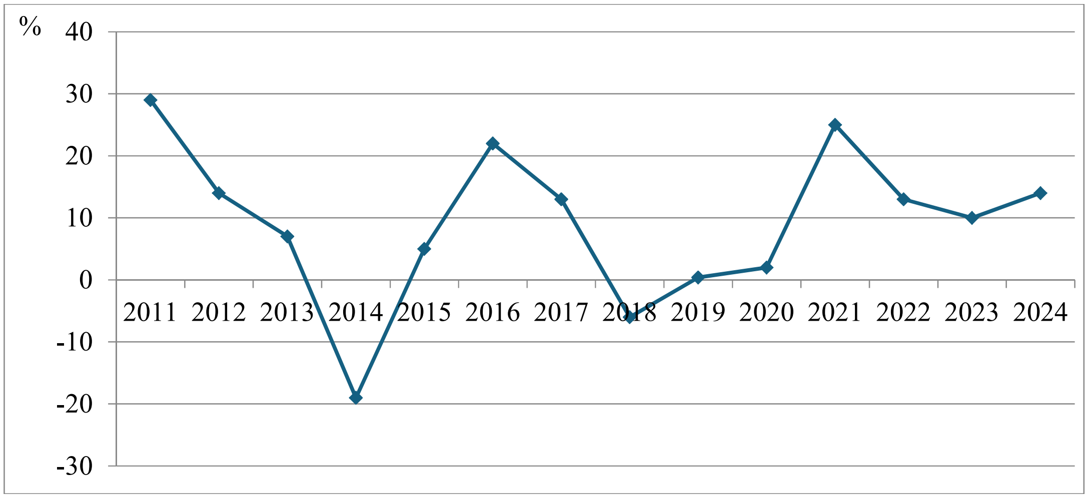

Fig. 5. Net profit margin of Astarta-Kyiv, 2011-2024.

Source: based on the Astarta-Kyiv (2025).

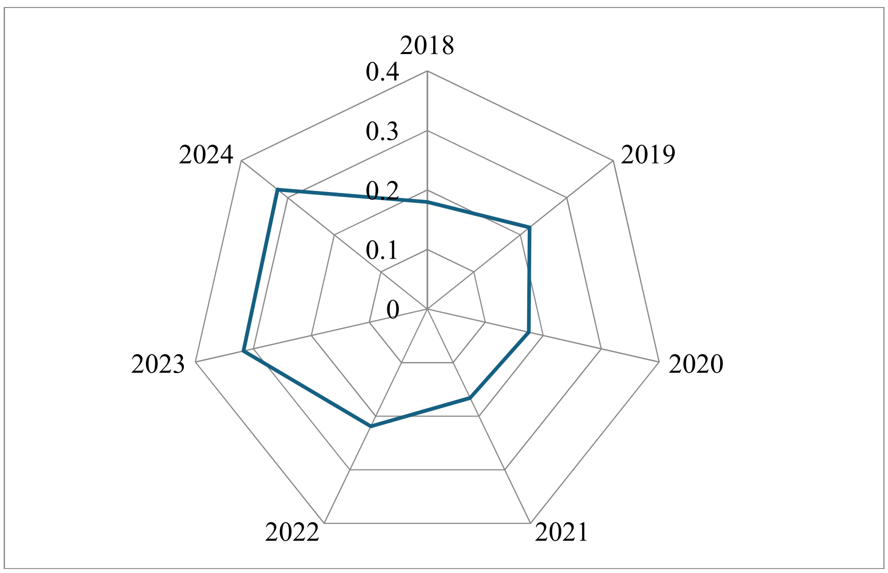

Fig. 6. ICT Specialists in AGRIChain Client Companies (%).

Source: based on the AGRIChain (2025).

Among AGRIChain's main clients are Astarta-Kyiv, Agroprodservice, and the agroholding Vitagro, whose net profit figures are shown in Figure 7.

The correlation coefficient between these two indicators was calculated based on the data on the net profit of enterprises and the number of digital tools. For a group of 41 companies using AGRIChain digital products, the coefficient was 0.776, indicating a high degree of dependence of net profit on the number of digital tools used in agricultural production. The largest companies in this group are Astarta-Kyiv, Agroprodservis, and Vitagro.

The p-value obtained from the one-way analysis of variance was 0.028, allowing us to conclude that the differences between the groups did not occur by chance. For the average profit value based on the performance of the 41 companies using AGRIChain digital products, profit dependence on the number of digital products was established (Formula 3).

$$Pr = 365.9A + 427.6 \quad (3)$$

For the estimated coefficients of the linear model, the p-value was 0.04 for the slope (angular coefficient) and 0.622 for the intercept (free coefficient).

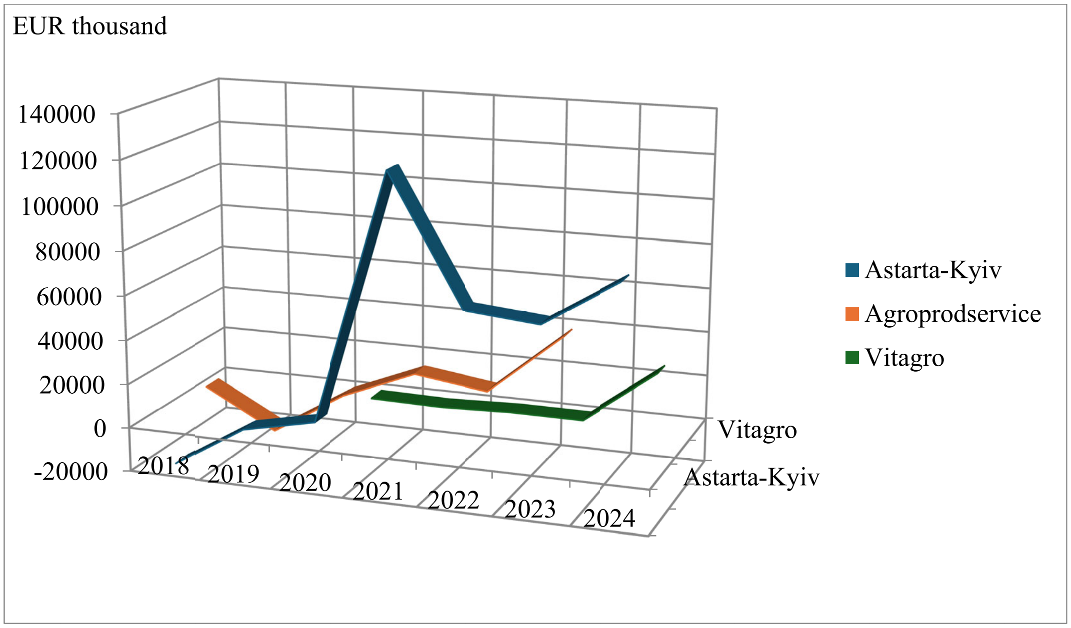

Fig. 7. Net Profit of AGRIChain's Main Client Companies, 2018–2024.
Source: based on the AGRIChain (2025).

Given these results, the model is statistically significant with respect to the slope and can be confidently used by AGRIChain specialists for marketing purposes and to estimate the potential number of projects that may need to be implemented during their operations. Kernel Digital has operated in the market since 2022 as a separate company. However, creating and implementing digital tools began earlier at Kernel, as the agricultural holding felt the need for digitalisation in 2015-2016, which led to several digital transformations within the company and the subsequent separation of Kernel Digital into an independent unit. According to a study of the labour force of 34 companies that use Kernel Digital products, the percentage of specialists with skills in working with information and communication technologies in these companies does not exceed 0.307% (Figure 8).

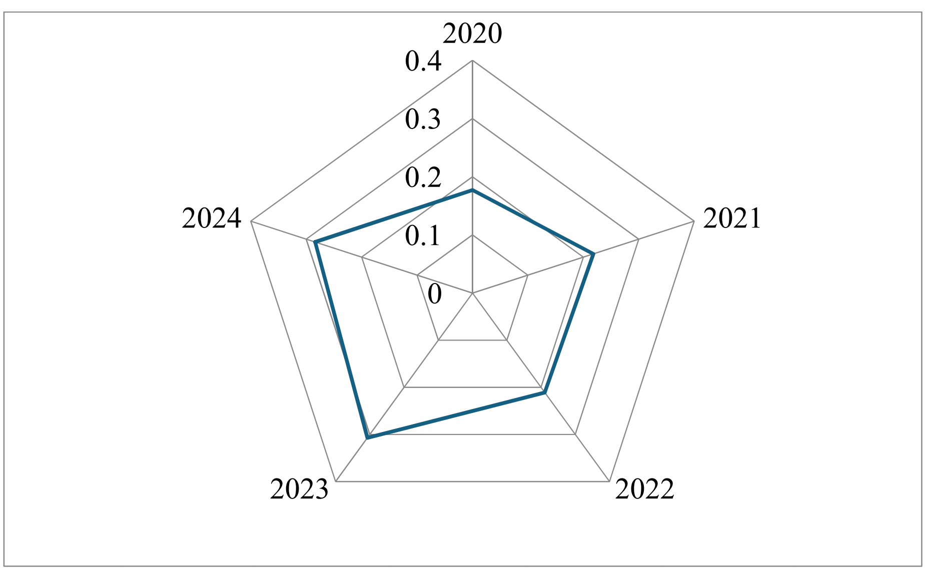

Fig. 8. ICT Specialists in Companies Using Kernel Digital Products, %.
Source: based on the Kernel Digital (2025).

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Based on data on enterprises' net profit and the number of digital tools used, the correlation coefficient between these two indicators was calculated as 0.902 for a group of 34 companies using Kernel Digital products. This indicates a strong dependence of net profit on the number of digital tools employed in agricultural production, with the most prominent companies being ZolotnikiAgro, STOV Gumenetske, and Hliborib. The p-value from a one-way ANOVA test was 0.002, allowing us to conclude that the differences observed between these groups are statistically significant and unlikely to have arisen by chance. Figure 9 shows the net profit results for the main users of Kernel Digital's digital tools.

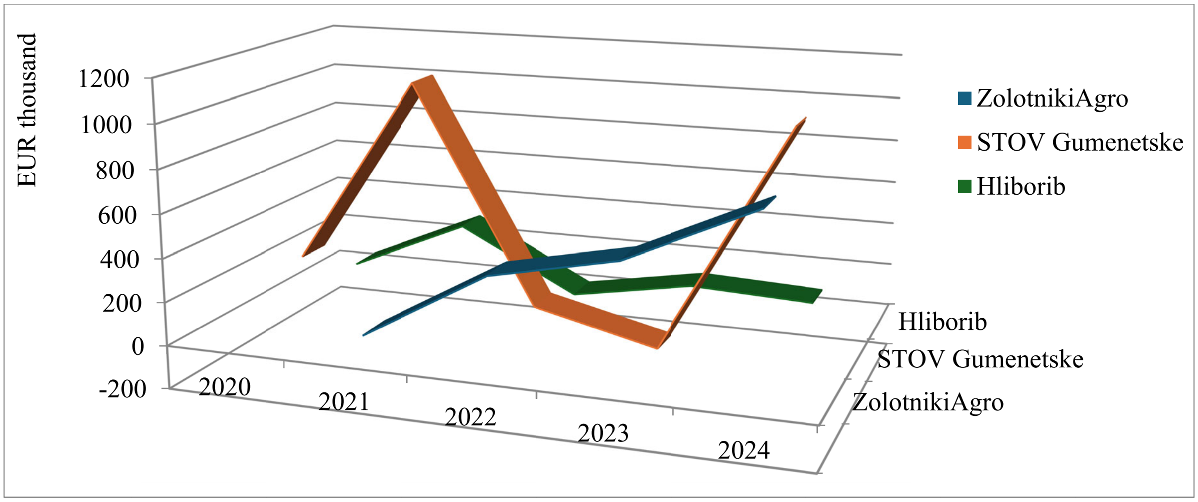

Fig. 9. Net Profit of Kernel Digital's Main Client Companies, 2020–2024.
Source: based on the Kernel Digital (2025).

For the average profit value based on the performance of 34 companies using Kernel Digital's products, profit dependence on the number of digital products was established (formula 4).

$$Pr = 13.13\,A + 11.13 \tag{4}$$

The p-values for the linear model coefficients were 0.04 for the slope and 0.475 for the intercept. Kernel Digital specialists may utilise this model for marketing purposes and to forecast the potential number of projects required during their operations.

5. Discussion.

The transition to a digital economy entails synchronising digitalisation efforts across industries. This enables the acquisition of complete and reliable information on resource availability, agricultural production methods, and characteristics of applied fertilisers, plant protection products, feed additives, and other data relevant to developing agricultural products.

Since agricultural production underpins human survival as a biological species, establishing information flows accompanying the entire agricultural process is vital for obtaining high-quality food. Such informational support is only possible through comprehensive and effective digital support for agricultural production.

A comprehensive approach to this issue is essential for integrating digital tools into the daily operations of agricultural enterprises. One of the key conditions for the digitalisation of agriculture is the compatibility of existing machinery and equipment with digital tools.

This can be achieved by upgrading vehicle fleets and incorporating innovative solutions at the level of the vehicle's individual technical or group components. To ensure general and seamless compatibility between digital tools, specialised communication modules are required to facilitate high-quality information exchange between technical and digital components and among different digital tools.

This comprehensive approach to the hardware aspect of agricultural digitalisation will enable the timely collection, processing, and dissemination of information for stakeholders to use effectively. For the optimal operation of digital tools, personnel must be adapted to these tools when performing specific production tasks. The digital competencies of agricultural workers are crucial for successfully implementing various digital tools. Against the backdrop of a broader interest in enhancing employee competencies, there is a need for specialised courses or modules within existing training programmes that can help align the education level, including digital competencies, with what is required for the effective application of digital tools in the workplace.

Unlike the EU, which has been monitoring the digital competencies of agricultural workers since 2016, Ukraine does not currently conduct such monitoring. This monitoring would provide direct insights into the number of digitally skilled workers and serve as an indirect incentive for farm managers by offering valuable information about their employees' digital literacy. Partial results obtained during this study, based on data from companies already actively using digital tools in agricultural production, indicate that Ukrainian agricultural enterprises are less equipped with ICT-skilled specialists than their European counterparts.

In Ukraine, digital agriculture products are developed and implemented by companies closely linked to major agricultural producers, making these products particularly practical and user-oriented. Agriculture has specific characteristics that shape the components of digital support uniquely suited to the sector. The study results show that the quantitative performance indicators of agricultural production are directly related to the number of digital products farmers use. This dependence further broadens the potential for the application of digital tools in various agricultural technological processes.

The outcomes demonstrate the potential for increasing the efficiency of agricultural production using digital tools (Gabriel & Gandorfer, 2023).

Confirming the assertion of Kramarz and Runowski (2025), the digitalisation of agriculture directly depends on the degree of farmers' readiness to adopt modern tools.

Furthermore, the hypothesis proposed by MacPherson et al. (2022) that a more flexible approach to improving agricultural workers' digital skills is needed was confirmed. The research questions were explored. However, new circumstances uncovered during this research suggest that future studies should focus on developing a typology of digital tools in agriculture. This would allow for a more qualitative and effective approach to enhancing the digital skills of agricultural workers, which would positively affect agricultural production performance indicators.

6. Conclusions.

The following conclusions can be drawn, considering the main aspects of the current state of agricultural digitalisation. Various digital tools are employed to improve the efficiency of agricultural production, with their range expanding as technologies advance in agriculture and other sectors of the economy.

Using digital tools stimulates comprehensive technological renewal in agricultural production, directly through the purchase of new equipment and indirectly through the local modernisation of existing technical means to synchronise them with digital devices. The development of a digital support system for agricultural production entails significant changes in the set of professional competencies required from workers, a reduction in their overall number (by 17.2% globally, 7% in the EU, and 5.2% in Ukraine between 1991 and 2023).

Additionally, there has been a decrease in the share of workers per 1% of added value in agriculture (by 3% globally and 1.5% in the EU over the same period). In contrast, Ukraine has seen an increase in the share of people employed in agriculture per 1% of added value (by 0.5% from 1991 to 2022). Unlike EU countries, where the share of agricultural workers with ICT skills has been monitored since 2016, no such monitoring currently exists in Ukraine.

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In the EU, this share peaked at 0.465% in 2017 and declined to 0.275% in 2023. However, its introduction could be integrated with monitoring digital tool usage, which is conducted only by companies that develop these tools. Results from clients of two companies involved in the development and implementation of digital tools in agriculture indicate that the percentage of ICT-skilled specialists in Ukraine is lower, reaching a maximum of 0.322% for AGRIChain clients in 2024 and 0.307% for Kernel Digital clients in 2023 than that in EU countries. Nevertheless, the trend is smoother and shows a gradual upward trajectory. A correlation analysis between net profit and the number of digital tools used by two independent Ukrainian developers of agricultural digital tools was performed.

The results show coefficients greater than 0.5 in both cases. Specifically, the correlation is 0.766 for 41 AGRIChain clients and 0.902 for 34 Kernel Digital clients. This indicates a significant positive relationship and underscores the importance of further expanding digital technologies in agricultural production.

The net profit models for groups of enterprises that are clients of these digital tool providers, developed during this study, demonstrate positive trends for both companies (slope coefficients of 365.9 for AGRIChain and 13.13 for Kernel Digital), among the largest in the Ukrainian market. This finding further supports the case for broadening the range and availability of digital tools in the agricultural sector of developing countries.

REFERENCES

Di Virgilio, F., Dimitrov, R., Dorokhova, L., Yermolenko, O., Dorokhov, O., & Petrova, M. (2023). Innovation factors for high and middle-income countries in the innovation management context. Access to Science, Business, Innovation in the Digital Economy, 4(3), 434–452. https://doi.org/10.46656/access.2023.4.3(8)

Ehlers, M.-H., Huber, R., & Finger, R. (2021). Agricultural policy in the era of digitalisation. Food Policy, 100, 102019, https://doi.org/10.1016/j.foodpol.2020.102019

Fernandez-Mena, H., Nesme, T., & Pellerin, S. (2016). Towards an Agro-Industrial Ecology: A review of nutrient flow modelling and assessment tools in agro-food systems at the local scale. The Science of the Total Environment, 543(Pt A), 467–479. https://doi.org/10.1016/j.scitotenv.2015.11.032

Fróna, D., & Szenderák, J. (2024). Digitalization and digital technologies: The obstacles to adaptation among Hungarian farmers. Equilibrium. Quarterly Journal of Economics and Economic Policy, 19 (3), 1075-1110. https://doi.org/10.24136/eq.3237

Gabriel, A., & Gandorfer, M. (2023). Adoption of digital technologies in agriculture—an inventory in a european small-scale farming region. Precision Agriculture, 24(1), 68–91. https://doi.org/10.1007/s11119-022-09931-1

Gajdosikova, D., & Michulek, J. (2025, 15(10)). Artificial Intelligence Models for Bankruptcy Prediction in Agriculture: Comparing the Performance of Artificial Neural Networks and Decision Trees. Agriculture, https://doi.org/10.3390/agriculture15101077

Garske, B., Bau, A., & Ekardt, F. (2021, 13(9)). Digitalization and AI in European Agriculture: A Strategy for Achieving Climate and Biodiversity Targets? Sustainability, 4652; https://doi.org/10.3390/su13094652

Guerrero-Ocampo, S. B., & Díaz-Puente, J. M. (2023, 15(18)). Social Network Analysis Uses and Contributions to Innovation Initiatives in Rural Areas: A Review. Sustainability, 14018; https://doi.org/10.3390/su151814018

Jorge-Vázquez, J., Chivite-Cebolla, M. P., & Salinas-Ramos, F. (2021). The digitalization of the European agri-food cooperative sector. Determining factors to embrace information and communication technologies. Agriculture, 11(6), 514. https://doi.org/10.3390/agriculture11060514

Kramarz, P., & Runowski, H. (2025). Possibilities of using digital technologies in agriculture in areas with high agrarian fragmentation. Precision Agriculture, 48, https://doi.org/10.1007/s11119-025-10244-2

Lacoste, M., Bellon-Maurel, V., Piot-Lepetit, I., Cook, S., Tremblay, N., Longchamps, L., . . . Hall, A. (2025). Farmer-centric On-Farm Experimentation: digital tools for a scalable transformative pathway. Agronomy for Sustainable Development, 18, https://doi.org/10.1007/s13593-025-01011-8

MacPherson, J., Voglhuber-Slavinsky, A., Olbrisch, M., Schöbel, P., Dönitz, E., Mouratiadou, I., & Helming, K. (2022). Future agricultural systems and the role of digitalization for achieving sustainability goals. A review. Agronomy for Sustainable Development, 70, https://doi.org/10.1007/s13593-022-00792-6

Șerbănel, C.-I. (2021). A panorama of digitalization tendencies in the European agriculture sector. Proceedings of the International Conference on Business Excellence, 15(1), 352–363. https://doi.org/10.2478/picbe-2021-0033

Singh, S., Singh, S. K., Singh, V. L., & Petrova, M. (2025). Unravelling economic complexity: A systematic exploration of themes and trends through literature and keyword network analysis. Access to Science, Business, Innovation in Digital Economy, 6(2), 357–380. https://doi.org/10.46656/access.2025.6.2(7)

Tey, Y. S., & Brindal, M. (2022). A meta-analysis of factors driving the adoption of precision agriculture. Precision Agriculture, 23(2), 353–372. https://doi.org/10.1007/s11119-021-09840-9

Weckesser, F., Beck, M., Hülsbergen, K.-J., & Peisl, S. (2022, 12(2)). A Digital Advisor Twin for Crop Nitrogen Management. Agriculture, 302; https://doi.org/10.3390/agriculture12020302