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DIGITALIZATION OF THE AGRICULTURAL SECTOR: THE IMPACT OF ICT ON THE DEVELOPMENT OF ENTERPRISES IN UKRAINE

Purpose. *The purpose of the research paper is determining the effect of information and communication technologies (ICTs) on the agricultural enterprises performance in Ukraine by studying the dependence of the performance of agricultural enterprises on the activity of their digital solutions implementation.*

Methodology / approach. *The effect of ICTs on the performance of agricultural enterprises is studied using the methods of average and relative values, dynamic analysis – in determining the trends in the development of enterprises of the ICT segment and the activity of implementation of digital solutions by agricultural enterprises in their practice; correlation analysis – in studying the dependence of the performance of agricultural enterprises on the activity of digital solutions implementation.*

Results. *The dependence of the performance of agricultural enterprises on the activity of their implementation of digital solutions is determined. A direct link between the volume of activities of enterprises operating in the ICT segment and the investments of agricultural enterprises in software is established. It has been determined that the activity of agricultural enterprises in terms of investments in software has a positive effect on their activities results, causing an increase in the volume of sold products, added value and labour productivity. A direct but weak effect of software investments on the cost efficiency of current and environmental activities has been diagnosed. A feedback relationship has been established between the investments made by agricultural enterprises in the acquisition of software and the profitability of their operating activities, which is increasing with taking into account the time lag.*

Originality / scientific novelty. *The article provides empirical evidence of the dependence of agricultural enterprises activity indices on ICT segment enterprises development. The dependence of the results of agricultural enterprises activity on the activity of their digital solutions implementation was investigated with and without taking into account the time lag. The scientific and methodological foundations for assessing the impact of ICT on the performance of enterprises have been improved, in particular by allocating indicators for this assessment by stages of research.*

Practical value / significance. *The results of the study can be used in the decision-making process regarding the digital transformation of agricultural enterprises through the implementation of ICT.*

Key words: *ICT, digitalization, digital transformation, agricultural enterprise, agriculture.*

Introduction and review of literature. Digitalization involves the integration of information and communication technologies (ICT) into all aspects of society. Digitalization has a significant effect on the development of various economic sectors, including agricultural enterprises, which face many challenges, such as low productivity, inefficient use of resources, high risk of natural disasters, climate change and global competition. In this context, digitalization is a powerful tool for improving the efficiency, competitiveness and sustainability of agricultural enterprises.

In order to identify the current research trends in the field of digitalization of agricultural enterprises, scientific sources obtained from the main collection of Web of Science were used. A combination of title (TI) and author keywords (AK) was used in the search for providing high relevance of the literature to the topic. The search strategy was as follows: (TI = (digital* AND agri*) OR AK= (digital* AND agri*)). The search covered the period from 1 January 2014 to 13 October 2023 and was limited to the publication types Article, Proceeding Paper, Review Article, and Early Access. A total of 1185 documents were selected for further review.

The CiteSpace 6.2.R4 software tool was used for identifying current research trends in the field of digitalization in agriculture. It allows the identification and visualization of new trends and transition patterns in the scientific literature on the base of citation network [1]. A total of 36 clusters were identified in the citation network, of which 9 are the most important (Table 1).

Table 1

The largest clusters identified for the collaborative citation network

Cluster ID	Size	Silhouette	Mean (year)	Top terms based on keywords (Log-likelihood ratio algorithm; p-level)
0	40	0.715	2019	responsible innovation (14.21, 0.001); affect (8.12, 0.005); digital soil mapping (7.83, 0.01); machine learning (7.41, 0.01); digitalization (7.02, 0.01)
1	30	0.933	2017	precision agriculture (54.24, 1.0E-4); machine learning (50.74, 1.0E-4); deep learning (47.65, 1.0E-4); digital soil mapping (44.16, 1.0E-4); digital agriculture (22.24, 1.0E-4)
2	30	0.689	2020	industry 4 (21.08, 1.0E-4); 0 (18.76, 1.0E-4); blockchain (13.62, 0.001); sensors (10.17, 0.005); digital soil mapping (8.78, 0.005)
3	29	0.741	2017	smart farming (12.49, 0.001); big data (10.69, 0.005); networks (8.48, 0.005); data governance (8.48, 0.005); responsible innovation (8.48, 0.005)
4	23	0.891	2018	ICT (30, 1.0E-4); information (16.25, 1.0E-4); Africa (12.83, 0.001); machine learning (11.81, 0.001); digital divide (11.16, 0.001)
5	19	0.748	2020	drivers (10.73, 0.005); adoption (9.18, 0.005); machine learning (6.68, 0.01); technology adoption (5.49, 0.05); smallholder farmers (5.49, 0.05)
6	15	0.961	2016	remote sensing (42.77, 1.0E-4); proximal sensors (11.67, 0.001); soil sensors (11.67, 0.001); sensors for crop monitoring (11.67, 0.001); electrical conductivity (11.67, 0.001)
7	8	1	2021	digital financial inclusion (50.85, 1.0E-4); agricultural green total factor productivity (33.76, 1.0E-4); digital inclusive finance (25.26, 1.0E-4); structural effect (8.38, 0.005); super SBM model (8.38, 0.005)
8	6	0.954	2020	agricultural extension (9.6, 0.005); farm (8.91, 0.005); user-centered design (8.91, 0.005); text mining (8.91, 0.005); subscribers (8.91, 0.005)
9	7	1	2020	digital twin (50.85, 1.0E-4); greenhouse (14, 0.001); smart agriculture (12.5, 0.001); IoT (8.07, 0.005); industrial control systems (6.99, 0.01)

Source: generated by CiteSpace.

The citation network and the corresponding clustering visualization generated by CiteSpace are shown in Figure 1.

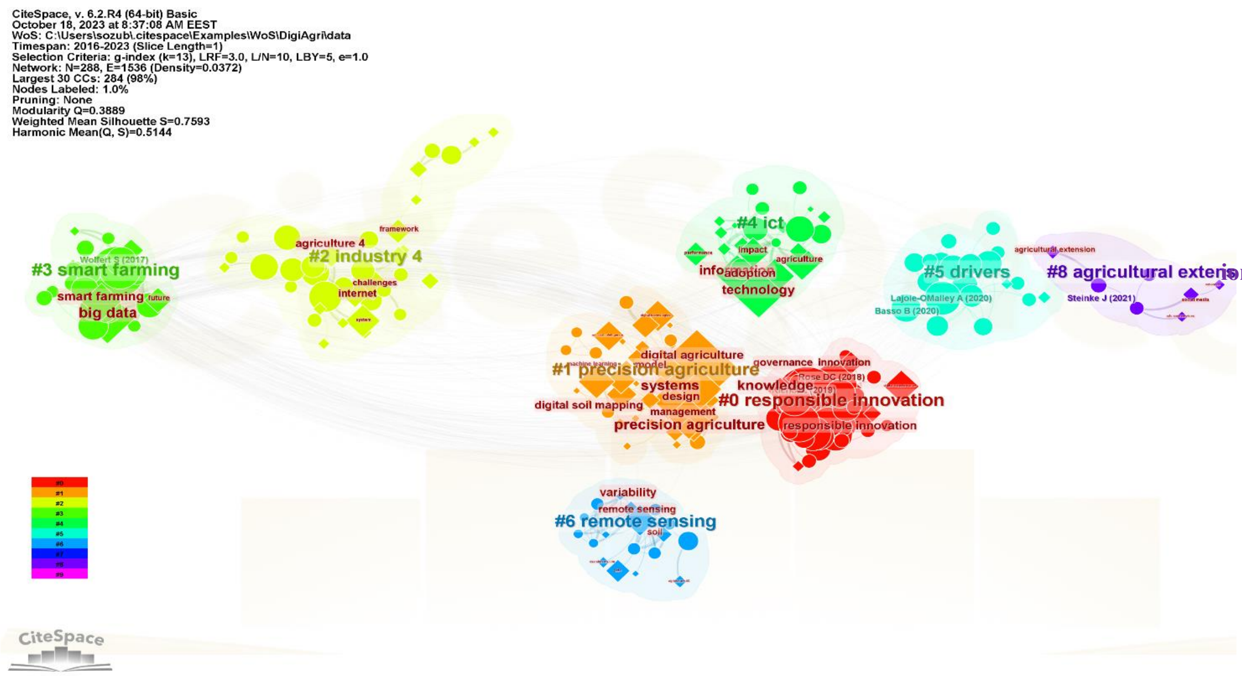

Figure 1. Co-citation network and corresponding clustering visualization

Source: generated by CiteSpace.

The first significant research trend is related to smart agriculture and is presented in research cluster #3, which started in 2017. The most important research paper in this research cluster is S. Wolfert et al. [2]. The paper explores various applications of big data in smart agriculture, such as precision farming, livestock management, and supply chain optimization. It discusses how big data analytics can help farmers make more informed decisions and optimize their operations. The authors also discuss potential future developments in big data in smart agriculture, including the integration of artificial intelligence and machine learning techniques for data analysis and decision support [2]. S. Qazi et al. emphasize the importance of the Internet of Things and artificial intelligence methods in agriculture and their potential for agricultural practices revolution through the introduction of smart farming methods and efficient resource management [3]. The paper [4] proposes a conceptual framework for smart agriculture and digital twins that includes four key stages: data collection, data processing, data analysis and assessment, and information use. Smart agriculture, which is based on information technology, sensors, autonomous vehicles, data analysis and predictive modelling, can help to improve food security, reduce water consumption, use of fertilizers and pesticides, and increase farm profitability [4].

The second important research trend relates to Industry 4.0, and is presented in research cluster #2, which started in 2020. In the research paper [5], the review focuses on appropriate approaches to data fusion and the stages of integrating DT implementation with Industry 4.0 technologies. The conclusions include the identification of the stages, which are required for creation of DT, data fusion processes, and the integration of Industry 4.0 technologies such as cloud, IoT, and artificial intelligence sub-sectors [5]. The study [6] focuses on the benefits and barriers of implementing Industry 4.0 technologies in the agricultural sector of developing countries. The study highlights the social and environmental effects of digital technologies in optimizing operations and resource use [6]. The paper [7] argues that digital innovations in agriculture involve the use of advanced technologies in food production, known as Agriculture 4.0, and are part of the fourth industrial revolution. Digital agriculture supports better decision-making through consistent analysis of agricultural systems using digital solutions related to robotics and artificial intelligence [7].

The third important research trend concerns precision agriculture and is presented in research cluster #1, which started in 2017 and is most closely related to all the other trends. The research paper [8] argues that data-driven agriculture using information and communication technologies (ICT) in precision agriculture is an important solution for efficient and well-regulated agriculture while preserving the climate [8]. Big data, including machine learning and deep learning, plays an important role in precision agriculture, providing important information and helping practitioners make accurate decisions [8]. The transition from precision agriculture to Agriculture 5.0 involves the introduction of the latest technologies, data management and automation in crop production [9]. The research paper [10] states that the concept of precision agriculture, which is based on information technology, is an attractive solution for managing natural resources and achieving modern and sustainable agricultural development, bringing the agricultural sector into the digital and information age [10].

The fourth major research trend relates to information and communication technologies and is presented in research cluster 4, which started in 2017 and is most closely related to all the other trends. New forms of digital information and communication technologies have the potential to provide the "next generation" of agricultural technologies that can help increase productivity and efficiency while reducing risks and negative effects [11]. Information and communication technology (ICT) innovations are playing an increasingly important role in agricultural research for development [12].

All the research trends are linked to the largest cluster #0, "responsible innovation". Successful responsible innovation requires systemic and organizational changes in R&D practices at different levels to enable and enhance the "responsiveness" of project teams, including changes in performance measures and reward mechanisms that encourage more responsible R&D outcomes. Responsible innovation adds value to R&D programmes in digital agriculture [12]. The key dimensions of responsible innovation – anticipation, inclusiveness, reflexivity and responsiveness – should be applied to the fourth agricultural revolution, driven by emerging technologies such as the Internet of Things, cloud computing, robotics and artificial intelligence [12].

In addition, we have identified several regional research areas in the field of agricultural digitalization.

In China, researchers are interested in digital financial inclusion [13–18]. Digital financial inclusion can increase the overall productivity of green inputs in agriculture by facilitating the transfer of agricultural land [13]. Digital financial inclusion has a significant positive effect on the efficiency of technological innovation in agricultural enterprises, can promote technological innovation through the mechanism of enterprise digitalization, and shows a growing trend towards improving the level of innovation in enterprises [14].

Cluster 8, agricultural extension, reflects the regional interest in transferring knowledge to farmers on the African continent [19–23].

The timeline map provides a visual representation of the duration and historical development of each cluster. It also allowed us to pinpoint the exact timing of the landmark publications. From Figure 2, we can see that the most recent research trend is cluster #7, digital financial inclusion. The earliest and still relevant research trend is cluster 4 "information and communication technologies".

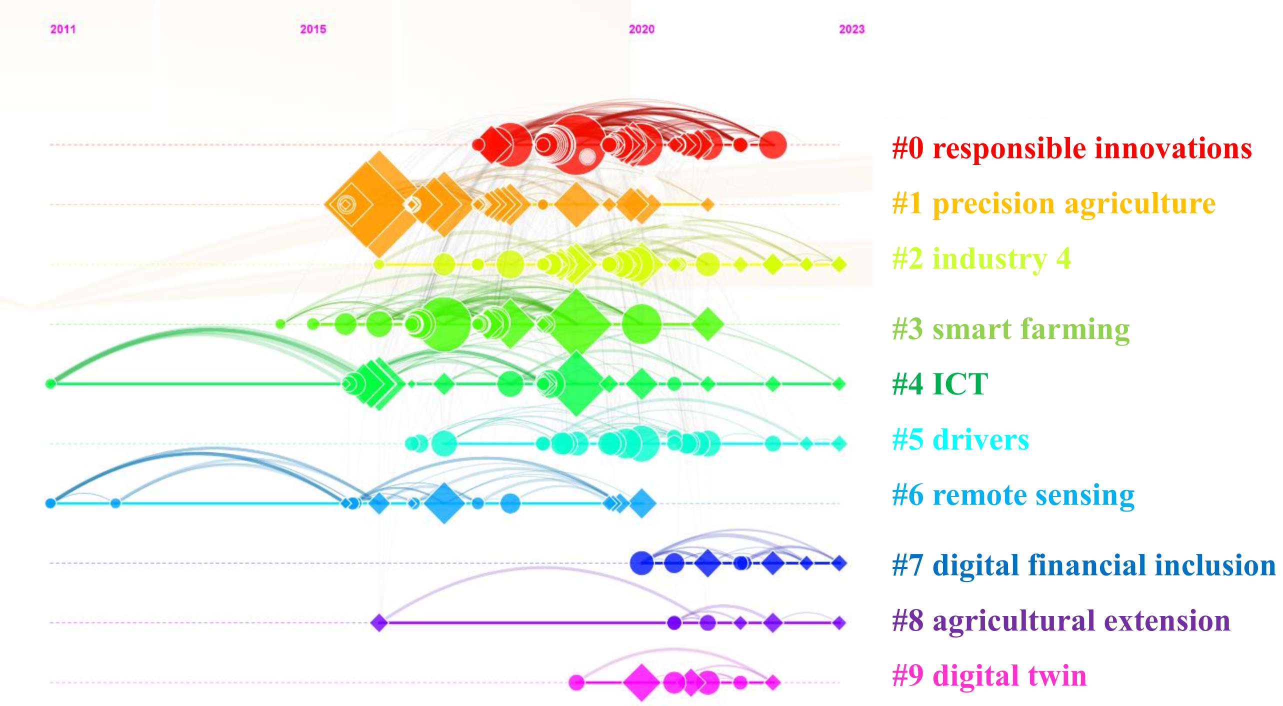

Figure 2. Timeline visualization of the citation network

Source: generated by CiteSpace.

Figure 3 shows the cooperation networks between countries created using the VOSviewer 1.6.19 software [24]. In total, 59 countries were analyzed, which are represented in 8 clusters. The People's Republic of China is in the center with the largest number of publications (n = 165), followed by the United States of America with 152 publications and Germany with 98 publications. Ukrainian researchers in this field are represented by 17 publications, with only 2 links to Germany and Belgium. The main studies focus on the use of information technologies in the management of agricultural enterprises [25–29]; the formation of digital competences in agriculture [30–31]; the introduction of digital technologies in smart agriculture [32–34]; the implementation of state policy in the field of agricultural digitalization [35–36].

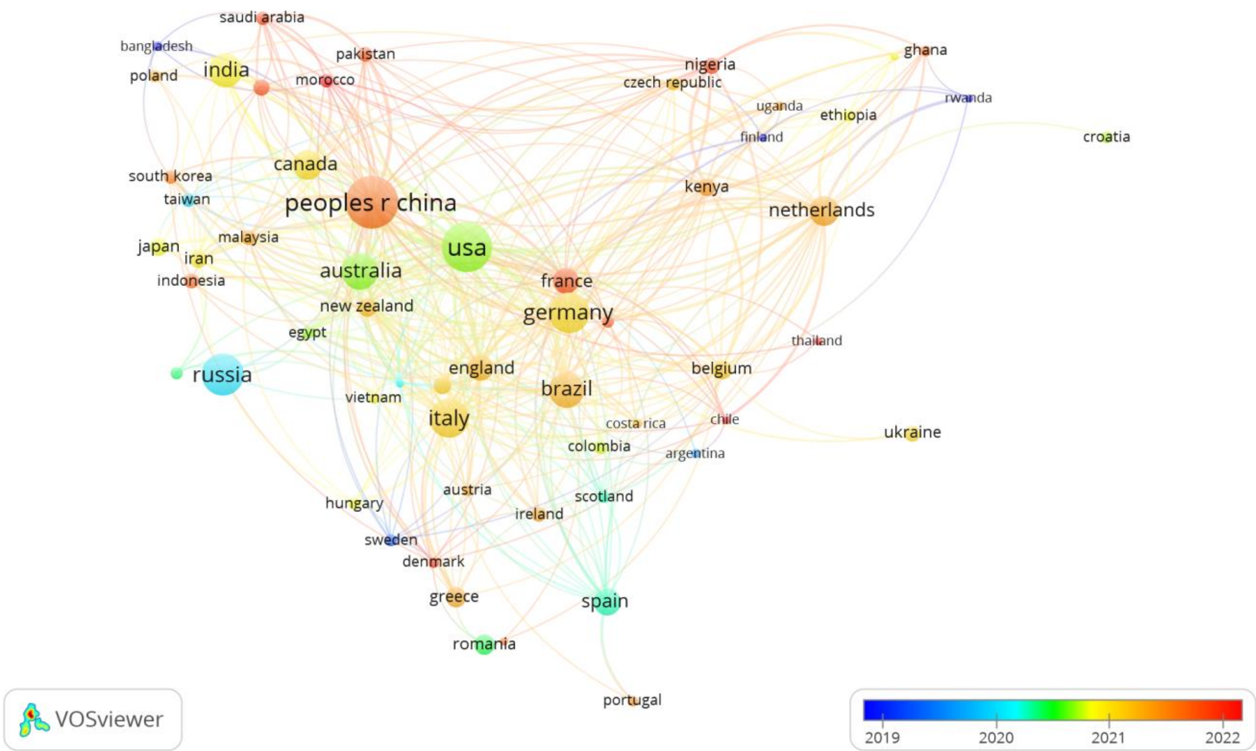

Figure 3. Cooperation network between countries

Source: generated by VOSviewer.

Consequently, ICT-based innovations in agricultural enterprises are playing an increasingly important role in agricultural research for the sustainable development. In view of this, it is objective to study the extent to which agricultural enterprises are receptive to the introduction of digital developments and to what extent the ICT implementation affects the performance of agricultural enterprises.

The purpose of the article. The purpose of the research paper is determining the effect of ICTs implementation on the performance of agricultural enterprises in Ukraine. For this purpose, the research paper identifies trends in the development of enterprises in the ICT segment; studies the activity of implementation of digital solutions by agricultural enterprises in their business practices; and investigates the dependence of the performance of agricultural enterprises on the activity of their implementation of digital solutions.

Methodology. The effect of ICTs implementation on the performance of agricultural enterprises is studied using the methods of average and relative values, dynamic analysis – in determining the trends in the development of enterprises of the ICT segment and the activity of implementation of digital solutions by agricultural enterprises in their practice; correlation analysis – in studying the dependence of the performance of agricultural enterprises on the activity of digital solutions implementation.

The study was conducted using data from the State Statistics Service of Ukraine. For determining the trends in the development of enterprises in the ICT segment, data on the performance of enterprises grouped by special aggregations provided for by

Regulation (EC) No. 251/2009 of 11 March 2009 [37] were used. For analyzing the activity of agricultural enterprises in implementing digital solutions in their business practices, data on enterprises belonging to Section A (agriculture, forestry and fishing) according to the classification of economic activities (NACE) were used.

The study was conducted using indicators that reflect: the performance of enterprises in the ICT segment; the implementation of digital changes by agricultural enterprises; the performance and efficiency of agricultural enterprises. To characterize the performance of the ICT segment enterprises, the indicator of the volume of activities of enterprises operating in the ICT segment (P_{ICT}) is used. Based on the investigations [38, p. 115; 39 p. 8], the indicator of investment in software acquisition (I_S) is used to assess the implementation of digital changes by agricultural enterprises. To characterize the performance and efficiency of agricultural enterprises, the indicators of the volume of products sold (P_{SE}), value added (AV_{SE}), labor productivity (PR_{SE}), efficiency of environmental protection costs (ENE_{SE}), efficiency of current activity costs (CCA_{SE}), and profitability of operating activities (CCA_{SE}) are used.

Information on the indicators of the volume of activity of enterprises operating in the ICT segment (P_{ICT}), investments of agricultural enterprises in software (I_S), indicators of the volume of activity of agricultural enterprises (P_{SE}), their added value (AV_{SE}), profitability of operating activities (R_{SE}) is taken from the materials of the State Statistics Service of Ukraine [37; 40–42]. The indicators of labor productivity (PR_{SE}), efficiency of environmental protection costs (ENE_{SE}), and current activity costs (CCA_{SE}) are calculated according to the State Statistics Service of Ukraine [40–42]. The formulas for calculation are as follows [43]:

$$PR_{SE} = \frac{P_{SE}}{E}, \quad (1)$$

$$ENE_{SE} = \frac{P_{SE}}{CE}, \quad (2)$$

$$CCA_{SE} = \frac{P_{SE}}{C}, \quad (3)$$

where E – number of employees, persons;

CE – environmental protection costs, million UAH;

C – costs of current operations of agricultural enterprises, million UAH.

The hypotheses of this investigation are formulated on the basis of the provisions contained in the scientific literature: the positive effect of ICT on labour productivity and the increase in value added, as stated in the publications [38, p. 33; 44, p. 92; 45]; the environmental friendliness of the activities, as stated in [46]; the efficiency of the functioning and development of the enterprise, formalized in terms of the reduction of operating costs and the increase in the profitability of production, as stated in [47, pp. 96, 103]. Given the above, the following hypotheses were formulated and tested in this study.

Hypothesis 1: There is a direct relationship between the performance of ICT enterprises and the investment of agricultural enterprises in software.

Hypothesis 2. There is a direct relationship between the investment of agricultural enterprises in software and the sales volume of their products.

Hypothesis 3: There is a direct relationship between the investment of agricultural enterprises in software and the volume of value added of these enterprises.

Hypothesis 4. There is a direct relationship between the investment in software of agricultural enterprises and the labour productivity of these enterprises.

Hypothesis 5. There is a direct relationship between the investment of agricultural enterprises in software and the efficiency of their expenditures on environmental protection.

Hypothesis 6: There is a direct relationship between the investment of agricultural enterprises in the purchase of software and the cost efficiency of their current operations.

Hypothesis 7. There is a direct relationship between the investment of agricultural enterprises in software and the profitability of their operating activities.

For these hypotheses testing, we used data from the State Statistics Service of Ukraine on the development of the ICT segment [37] and agricultural enterprises [40–42]. The research period was 2010–2021.

For studying the relationship between the performance indices of enterprises of the ICT segment and agricultural enterprises, the method of correlation analysis is used, the essence of which is determining the direction and strength of the relationship between the variables. Correlation analysis was performed using MS Excel 2019.

A linear correlation coefficient was used for assessing the relationship between the variables [48]. Formula (4):

$$r_{xy} = \frac{n\sum_{i-1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{n\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2}\sqrt{n\sum_{i=1}^{n} y_i^2 - (\sum_{i=1}^{n} y_i)^2}}, \quad (4)$$

where r_{xy} – correlation coefficient;

n – number of observations;

x_i – independent variable;

y_i – dependent variable.

The dependence between the variables is determined on the base of the correlation coefficient, the value of which ranges from (-1.0) to (+1.0). The condition for determining the closeness of the relationship between the variables is as follows: the closer correlation coefficient (by module) is to one, the closer relationship between the variables under study. The condition for determining the direction of the relationship between the variables is as follows: if the correlation coefficient is positive, a direct relationship is diagnosed; if the correlation coefficient is negative, an inverse relationship between the variables under study is diagnosed. A correlation coefficient equal to zero indicates the absence of a linear correlation between the studied indices; a correlation coefficient equal to (+1.0) indicates a direct correlation, and a correlation coefficient equal to (-1.0) indicates an inverse functional relationship between the variables.

The study took into account the time lag. The study was conducted for one year without taking into account the time lag, and the correlation coefficients were calculated assuming that the dependent and independent variables were taken for the *t-th* period. When the study was conducted with a time lag, the correlation coefficients were calculated assuming that the independent variables were taken for the *t-th* period *and the* dependent variables for the *(t+n)th* period [49].

Results and discussion. In order to study the trends in the development of ICT enterprises, it is important to define the types of activities in this sector. In this paper, it is assumed that the ICT sector is formalized by enterprises engaged in ICT production and ICT services [44]. In research [44, p. 19], the authors state that such enterprises should include those engaged in the production of electronic devices for final consumption, data center components, elements of electronic networks (ICT production), as well as those providing services for the development and implementation of ICT, software maintenance, and database support (ICT services).

On the base of the provisions on the representation of the ICT segment by enterprises of the ICT production and ICT services sectors [44, pp. 19, 25] and with taking into account the information support for determining the trends in the development of the ICT segment, the performance indices of enterprises grouped by special aggregations provided for in Regulation (EC) No. 251/2009 of 11 March 2009 are used [37]. According to the published data, the enterprises of the Information and Communication Technologies (ICT) segment are represented by the enterprises of the segments Information and Communication Technologies in Production (ICT in Production) and Information and Communication Technologies in Services (ICT in Services) (Table 2).

Table 2

Volume of products (goods, services) sold by enterprises of the ICT sector in Ukraine in 2010–2021

Year	ICT, million UAH		
	in total	in production	in services
2010	62978.8	4611.1	58367.7
2011	75503.0	9382.3	66120.7
2012	85914.1	5388.0	80526.1
2013	88449.9	5063.3	83386.6
2014	97718.3	5082.2	92636.0
2015	117826.1	4539.0	113287.1
2016	150681.9	6349.7	144332.2
2017	188042.5	6637.8	181404.7
2018	230821.6	8588.5	222233.1
2019	261481.0	7497.4	253983.7
2020	293258.0	7392.5	285865.4
2021	377631.3	8500.5	369130.8

Source: compiled based on data from [37].

The volume of products (goods, services) sold by enterprises of the ICT sector of Ukraine in 2021 amounted to UAH 377631.3 million, which is 28.8 % more than in the previous year. The study found that the volume of products (goods and services) sold by Ukrainian ICT companies increased in 2010–2021, with the fastest growth in the Information and Communication Technologies in Services (ICT in Services) segment. During the analyzed period, the volume of products (goods and services) sold by enterprises in the segment of information and communication technologies in Ukraine increased by 6.0 times, including 1.8 times for enterprises in the segment of information and communication technologies in production and 6.3 times for enterprises in the segment of information and communication technologies in services. ICT enterprises in the segment of information and communication technologies in services are characterized not only by faster growth in the volume of products sold, but also by a larger share of these products in the total volume of products sold by ICT enterprises. In the structure of products sold by ICT enterprises, the share of enterprises in the Information and Communication Technologies in Services segment ranges from 87.6 to 97.7 %, while the share of enterprises in the Information and Communication Technologies in Production segment ranges from 1.4 to 2.3 % over time.

An increase in the share of products sold by ICT enterprises in the total volume of products sold by enterprises by type of economic activity was observed (Table 3).

Table 3

The share of sold products (goods, services) by ICT sector enterprises in the total volume of sold products of Ukrainian enterprises in 2010–2021

Years	Information and communication technologies, %		
	in total	in production	in services
2010	1.9	0.1	1.7
2011	1.9	0.2	1.7
2012	2.0	0.1	1.9
2013	2.2	0.1	2.1
2014	2.3	0.1	2.2
2015	2.3	0.1	2.2
2016	2.4	0.1	2.3
2017	2.4	0.1	2.4
2018	2.5	0.1	2.4
2019	2.7	0.1	2.6
2020	2.9	0.1	2.8
2021	2.7	0.1	2.7

Source: compiled from [37].

During the study period (2010–2021), this indicator increased from 1.9 % in 2010 to 2.7 % in 2021. This is primarily due to an increase in the share of sales of enterprises operating in the information and communication technologies in services segment. The share of products sold by enterprises in this segment increased from 1.7 % in 2010 to 2.7 % in 2021, while the share of enterprises in the information and communication technologies in production segment didn't exceed 0.1 % over the same period (except in 2011).

In terms of the number of enterprises operating in the ICT segment and the number of persons employed, the opposite trends were diagnosed during the analyzing period, i.e. an increase in the number of enterprises and a decrease in the number of persons employed (Table 4).

Table 4

Number of enterprises and number of persons employed in the ICT segment in 2010–2021

Year	Number of enterprises, units			Number of persons employed, thousands of people		
	in total	in production	in services	in total	in production	in services
2010	9220.0	500.0	8720.0	198.6	23.7	174.8
2011	9882.0	466.0	9416.0	200.9	28.4	172.4
2012	10225.0	397.0	9828.0	190.9	18.7	172.1
2013	11562.0	438.0	11124.0	188.9	16.8	172.1
2014	10534.0	375.0	10159.0	164.0	11.6	152.4
2015	10998.0	354.0	10644.0	140.7	10.3	130.3
2016	9979.0	286.0	9693.0	132.2	11.0	121.2
2017	11271.0	285.0	10986.0	129.0	10.7	118.3
2018	12291.0	293.0	11998.0	127.9	10.3	117.6
2019	13521.0	320.0	13201.0	136.5	10.4	126.1
2020	13829.0	350.0	13479.0	136.4	10.2	126.2
2021	14040.0	365.0	13675.0	135.5	10.5	125.0

Source: compiled from [37].

It should be noted that the share of enterprises in the information and communication technologies segment as a percentage of their total number is 2.4–3.8 % and is increasing over time. The share of persons employed in the ICT sector in the total number of employed persons is 2.1–2.6 % and has been decreasing over the years. From 2018 to the present, the share of persons, which are employed in the ICT sector has been set at 2.1 % of the total number of employed persons [37].

The combination of information on sold products, the number of enterprises and the number of employees makes it possible to identify trends in the development of enterprises operating in the ICT segment (Table 5).

The calculations show an average increase in the volume of sold products per enterprise in the ICT sector. This is due to the fact that the volume of sold products is growing faster than the number of enterprises in this economic activity. In 2021, compared with 2010, the volume of sold products in the ICT segment as a whole increased by 6.0 times, while the number of enterprises increased by 1.5 times. The opposite trend is observed for the number of persons, which are employed in the ICT segment. Between 2010 and 2021, the number of persons, which are employed in the ICT sector will decrease by 1.5 times, including 2.2 times in the Information and Communication Technologies in Production segment and 1.4 times in the Information and Communication Technologies in Services segment. This is the main reason for the decline in the average number of persons, which are employed in an ICT enterprise, as well as in enterprises in the ICT production and ICT services sectors.

Table 5

Performance of companies operating in the ICT production and services segment

Year	Volume of sold products per enterprise, million UAH/1 enterprise			Number of employees per enterprise, persons/enterprise		
	ICT	ICT in production	ICT in services	ICT	ICT in production	ICT in services
2010	6.8	9.2	6.7	22	47	20
2011	7.6	20.1	7.0	20	61	18
2012	8.4	13.6	8.2	19	47	18
2013	7.7	11.6	7.5	16	38	15
2014	9.3	13.6	9.1	16	31	15
2015	10.7	12.8	10.6	13	29	12
2016	15.1	22.2	14.9	13	38	13
2017	16.7	23.3	16.5	11	38	11
2018	18.8	29.3	18.5	10	35	10
2019	19.3	23.4	19.2	10	33	10
2020	21.2	21.1	21.2	10	29	9
2021	26.9	23.3	27.0	10	29	9

Source: compiled from [37].

The perception of ICT as a factor of efficiency and enterprise development determines the objectivity of the study of the development dynamics effect of this economy segment on enterprises economic activity other types. Agricultural enterprises play an important role in the development of Ukrainian economy. According to the data of 2022, agricultural enterprises accounted for 6.0 % of total sold products [50]; of the total number of enterprises by type of economic activity, 12.5 % operate in the segment of production and sale of agricultural products [51].

The development of the ICT sector leads to the transformation of enterprises in other types of economic activities, contributing to their efficient functioning and competitiveness. The introduction of ICT technologies in the agricultural sector has led in improvements in land cultivation, agrotechnical measures, field management, and the use of services for optimizing the financial and economic performance of agricultural enterprises. Published data indicate the active digitalization of agricultural enterprises, particularly in the use of digital platforms, precision farming technologies, land bank management, and the introduction of integrated solutions for automation and control of agricultural production processes [52]. According to the sectoral map of the digital economy, agriculture belongs to the sectors of ICT diffusion with a priority in the use of the Internet of Things and connected devices [38, pp. 15, 32, 43]. According to the World Economic Forum, the most promising for implementation in the agricultural segment are Climate-change mitigation technology, Environmental management technologies, Digital platforms and apps [53, p. 77]. A factor and a sign that agricultural enterprises are implementing digital changes is the investment of agricultural enterprises in the purchase of software.

The results of the analysis showed the instability of agricultural enterprises' investments in ICT technologies and services (Table 6).

Table 6

Investment in software by agricultural enterprises

Year	Capital investments in intangible assets, million UAH	Investments in software purchases, million UAH	Share of investments in software purchase of total investments in intangible assets, %
2010	48.6	8.1	16.7
2011	83.5	9.0	10.8
2012	65.5	19.2	29.3
2013	341.1	15.3	4.5
2014	75.5	24.5	32.5
2015	179.0	25.6	14.3
2016	271.4	36.9	13.6
2017	608.2	51.0	8.4
2018	1322.9	58.1	4.4
2019	1424.0	39.2	2.8
2020	901.4	44.1	4.9

Source: compiled from [40–42].

Between 2010 and 2018, investments in software increased gradually each year, with an average increase of 18 % per year. After 2018, spending on software purchases by agricultural holdings decreased. In 2019 and 2020, investments in software will amount to UAH 39.2 million and 44.1 million, which is 32.5 % and 24.1 % less than in 2018, respectively. Between 2010–2020, an uneven structure of investments in intangible assets in the segment of agricultural enterprises was diagnosed, namely the share of investments in the purchase of software. According to the 2020 data, this share was 4.9 %, which is higher than in 2019, when it was 2.8 %, but significantly lower than in previous periods. For comparison, the share of investments in software by agricultural enterprises in total investments in intangible assets was between 10.8 % and 32.5 % in 2010–2016 (excluding 2013).

The next stage of the study is to test the hypotheses on the effect of ICT on the economic development of agricultural enterprises. In order to study the effect of ICTs on the activities of agricultural enterprises, the correlation coefficients between the indices of the volume of activities of enterprises operating in the ICT segment (P_{ICT}), ICT in production (P_{ICTP}), ICT in services (P_{ICTS}), and investments of agricultural enterprises in software (I_S) are calculated. The relationship between agricultural enterprises' investments in software (I_S) and indices of their business volume (P_{SE}), added value (AV_{SE}), labour productivity (PR_{SE}), the efficiency of environmental protection costs (ENE_{SE}) and current activity costs (CCA_{SE}), and profitability of operating activities (R_{SE}) was also investigated.

The study of the dependence of the volume of activity of enterprises operating in the ICT segment and investments of agricultural enterprises in software (hypothesis 1) revealed a close direct relationship between these indices. The correlation coefficient without taking into account the time lag is 0.85. It is determined that when the time lag is taken into account, the dependence between the studied indices is weakened. However, even after 2–3 years, the relationship between the development of ICT and agricultural enterprises remains noticeable. According to the results of the calculations, the correlation coefficient between the sales volume of the ICT segment and investments of agricultural enterprises, taking into account the time lag of 2 and 2 years, was diagnosed at the levels of 0.65 and 0.56, respectively (Table 7).

Table 7

Correlation coefficients between the indices of the volume of activity of the enterprises operating in the ICT segment and investments of the agricultural enterprises in software

Indicator	$I_{S\ t}$	$I_{S\ t+1}$	$I_{S\ t+2}$	$I_{S\ t+3}$
$P_{ICT\ t}$	0.85	0.76	0.65	0.56
$P_{ICTP\ t}$	0.40	0.26	-0.10	-0.27
$P_{ICTS\ t}$	0.85	0.76	0.67	0.57

Source: calculated by the authors.

Correlation coefficients between volume indices of the enterprises operating activity in segments of ICT in production, ICT in services, and investments of agricultural enterprises in software show that a stable direct relationship exists only in the chain "ICT segment enterprises in services – agricultural enterprises". The relation in the chain "ICT segment enterprises in production – agricultural enterprises" is weak and changes to the opposite over time.

The effect of the activity of agricultural enterprises in the introduction of ICT technologies on the results of their activities is calculated (Table 8).

Table 8

Correlation coefficients between the indices of investment in software by agricultural enterprises and their performance

Indicator	Correlation coefficients between the indices of investment of agricultural enterprises in software and			
-	the scope of activities			
-	$P_{SE\ t}$	$P_{SE\ t+1}$	$P_{SE\ t+2}$	$P_{SE\ t+3}$
$I_{S\ t}$	0.90	0.81	0.79	0.94
-	value added			
-	$AV_{SE\ t}$	$AV_{SE\ t+1}$	$AV_{SE\ t+2}$	$AV_{SE\ t+3}$
$I_{S\ t}$	0.79	0.65	0.79	0.94
-	labour productivity			
-	$PR_{SE\ t}$	$PR_{SE\ t+1}$	$PR_{SE\ t+2}$	$PR_{SE\ t+3}$
$I_{S\ t}$	0.92	0.89	0.86	0.84
-	cost-effectiveness of environmental protection			
-	$ENE_{SE\ t}$	$ENE_{SE\ t+1}$	$ENE_{SE\ t+2}$	$ENE_{SE\ t+3}$
$I_{S\ t}$	0.33	0.16	0.06	0.25
-	cost-effectiveness of current operations			
-	$CCA_{SE\ t}$	$CCA_{SE\ t+1}$	$CCA_{SE\ t+2}$	$CCA_{SE\ t+3}$
$I_{S\ t}$	-0.46	-0.42	-0.15	0.10
-	profitability of operating activities			
-	$R_{SE\ t}$	$R_{SE\ t+1}$	$R_{SE\ t+2}$	$R_{SE\ t+3}$
$I_{S\ t}$	-0.05	-0.16	-0.21	-0.13

Source: calculated by the authors.

The calculations show that an increase in investment in software by agricultural enterprises leads to an increase in sales (Hypothesis 2) and value added (Hypothesis 3). The correlation coefficients indicate a direct strong relationship between the studied indices. The correlation coefficients between these factors without taking into account the time lag are 0.90 and 0.79, respectively. The relationship between these factors remains strong over time. The correlation coefficient between the agricultural enterprises' investments in software and the volume of their activities, which is calculated with taking into account the time lag, ranges from 0.79 to 0.94; between the volume of the agricultural enterprises' investments in software and their value added – from 0.65 to 0.94.

On the base of the calculations, we also found a direct close relationship between investment in software and labour productivity at agricultural enterprises (hypothesis 4). The correlation coefficient between these factors, without taking into account the time lag, is 0.92. Over time, the effect of software-related investment expenditure on agricultural labour productivity decreases somewhat, but remains high. This is confirmed by the correlation coefficient, which ranges from 0.84 to 0.89.

The hypotheses about the dependence of the efficiency of costs associated with environmental protection and current activities of agricultural enterprises on the activity of their ICT technology implementation (hypotheses 5 and 6) were partially confirmed. The relationship between investment in software and environmental protection expenditures is direct but weak. The correlation coefficients are 0.33 and 0.06–0.25 without and with a time lag, respectively. There is a multidirectional relationship between investment in software and the efficiency of current operations: a direct weak relationship when a three-year time lag is taken into account and a significant inverse relationship when other variants of correlation estimation are used. The correlation coefficients have the following values: 0.10 – in the case of a three-year time lag, from (-0.15) to (-0.46) – under other conditions of assessing the dependence of the efficiency of current activity costs on the activity of implementing ICT solutions in the practice of agricultural enterprises.

The hypothesis of a direct relationship between agricultural enterprises' investments in software and the profitability of their operating activities (Hypothesis 7) was not confirmed. An inverse relationship has been diagnosed between these indices, which increases over time. This is evidenced by the correlation coefficients, which values are negative and increase modulo the time lag. The correlation coefficients are (-0.05) and (-0.13) – (-0.21) without and with the time lag, respectively.

Summarizing the results of the study, we note the practical aspects of its use. Thus, the calculations confirmed the position that the introduction of ICT in the practice of agricultural enterprises has a positive impact on their performance and labor productivity, which is an argument for continuing digital transformations in the farms that implement them. At the same time, the low and sometimes negative values of the correlation coefficients between investment in ICT and the indicators of cost efficiency and profitability of agricultural operations indicate the need to assess the implementation of ICT not only in the whole farm, but also taking into account activities along the entire value chain.

Discussion. It should be noted that despite the relevance of the issue of introducing ICT into the practice of enterprises, there is still no unified methodological approach to conducting research in this area. At the same time, the use of correlation analysis as a tool for establishing links between the characteristics and research of enterprises of a certain segment of the national economy in the context of assessing the results of ICT implementation is what determines the commonality of our approach to conducting research with other published developments. In particular, with the research [39], in which the model of value added in agriculture is built using statistics on the cost of software and databases [39, p. 8]. Also, with the work [54], which presents the results of a study of the impact of ICT on supply chain management, in particular, the dependence of the flexibility of the supply chain management system on IT skills and knowledge, integration of IT-based systems, IT infrastructure, as well as the implementation of GPS and GIS technologies [54]. The study used a correlation analysis, the results of which, as in our study, confirmed the hypotheses, in particular, the positive impact of the introduction of ICT technologies on the activities of enterprises, in particular, the flexibility of the supply chain management system. As well as the work of [55], which considers the implementation of ICT as a business strategy to increase the profitability of enterprises. Although, unlike the above publication [55], in which the object of research was small and medium-sized enterprises, our study is related to the impact of ICT on the activities of enterprises in a particular sector of the economy, the hypotheses put forward and the results obtained are similar, in particular, regarding the consideration of ICT as a factor in the profitability of enterprises. We should also note the publication [38], which states that "the profitability of activities does not correlate with the growth rate of their capital investment in software" [38, p. 115], which confirms the results of our study on the feedback between investment in software and the profitability of the enterprise.

At the same time, the difference between our study and the above-mentioned ones lies in the methodological and applied aspects of research, in particular, the use of the characteristic of the activity of ICT implementation as an effective and factor sign of the impact of ICT on the development of enterprises.

Conclusions. This paper investigates the effect of ICT on the performance of agricultural enterprises in Ukraine. On the base of the study results on the performance indices of the ICT segment, the activity of agricultural enterprises in terms of software investments, and the dependence of agricultural enterprises' performance on the implementation of digital solutions, the following conclusions are drawn.

It is established that the volume of products sold by enterprises of the ICT sector of Ukraine in 2021 amounted to UAH 377631.3 million, which is 28.8 % more than in the previous year. The authors diagnose an increase in the share of sold products of ICT enterprises in the total volume of sold products by enterprises by type of economic activity from 1.9 % in 2010 to 2.7 % in 2021. It is established that in 2010–2021 there was an increase in the volume of sold products and a decrease in the number of employees per ICT segment enterprise on average.

On the base on the study results of indices of investment in software by agricultural enterprises, it is determined that investment in software by agricultural enterprises in the period of 2010–2021 was uneven. It is noted that, against the background of the growth of the absolute value of these investments, their share in the total volume of investments in intangible assets has been decreasing since 2016.

With regard to the hypotheses on the effect of ICT on the performance of agricultural enterprises, the calculations have established a direct relationship between the volume of activities of enterprises operating in the ICT segment and the investments of agricultural enterprises in software. It was found that the activity of agricultural enterprises in terms of investments in software has a positive effect on the results of their activities, causing an increase in the volume of sold products, added value, and labour productivity. A direct, but weak, effect of investment in software on the efficiency of current and environmental activities has been diagnosed. A feedback relationship has been established between the investments made by agricultural enterprises in the acquisition of software and the profitability of their activities, which, taking into account the time lag, is increasing.

Limitations and future research. We should also note the limitations of this study, which relate primarily to information support, which did not allow expanding the composition of indicators for the introduction of ICT in agricultural enterprises. We also note the macroeconomic aspect of the results obtained, and therefore the limited use of these results in the context of certain agricultural enterprises.

However, given the relevance of issues related to the digitalization of enterprises, scientific research in the direction of studying the dependence of economic development of enterprises on the activity of their ITC implementation is still needed. Further research should focus on issues related to the practice of implementing ICT in the activities of agricultural enterprises, taking into account the level of their digital maturity.

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