CIRCULAR ECONOMY AND DIGITAL TECHNOLOGIES AS DRIVERS OF SUSTAINABLE DEVELOPMENT OF THE AGRICULTURAL SECTOR OF THE REGION IN UKRAINE

ECONOMIA CIRCULAR E TECNOLOGIAS DIGITAIS COMO IMPULSIONADORES DO DESENVOLVIMENTO SUSTENTÁVEL DO SETOR AGRÍCOLA DA REGIÃO DA UCRÂNIA

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Abstract. The article examines modern challenges for the sustainable development of the agricultural sector in the regions of Ukraine based on the integration of the principles of the circular economy and digital technologies. It was determined that in modern conditions of economic instability, the agricultural sector needs new approaches to the use of resources and management of production processes. It has been proven that the circular economy offers a model where the resource circle is closed, reducing waste and the volume of raw material use based on reuse, recycling and disposal of materials, significantly reducing the ecological burden on the environment. Digital technologies that act as catalysts for this process, providing effective tracking of resources, optimisation of production processes and increased transparency in supply chains of the agricultural sector, are considered. Innovative solutions that can be used to implement the circular model in the production and resource processes of the region`s agricultural industry have been identified. Prospects for increasing the competitiveness of the Ukrainian agro-industrial complex through digitisation and greening of processes, which will contribute to sustainable economic growth and preservation of natural resources for future generations, are considered.

Keywords: digitisation, circular economy, agricultural sector, regional economy, sustainable development.

Resumo. O artigo examina os desafios modernos para o desenvolvimento sustentável do setor agrícola nas regiões da Ucrânia com base na integração dos princípios da economia circular e das tecnologias digitais. Foi determinado que, em condições modernas de instabilidade econômica, o setor agrícola precisa de novas abordagens para o uso de recursos e gestão dos processos de produção. Foi comprovado que a economia circular oferece um modelo onde o círculo de recursos é fechado, reduzindo o desperdício e o volume de uso de matéria-prima com base na reutilização, reciclagem e descarte de materiais, reduzindo significativamente a carga ecológica sobre o meio ambiente. São consideradas tecnologias digitais que atuam como catalisadores para esse processo, fornecendo rastreamento eficaz de recursos, otimização de processos de produção e maior transparência nas cadeias de suprimentos do setor agrícola. Foram identificadas soluções inovadoras que podem ser usadas para implementar o modelo circular nos processos de produção e recursos da indústria agrícola da região. São consideradas as perspectivas para aumentar a competitividade do complexo agroindustrial ucraniano por meio da digitalização e ecologização de processos, o que contribuirá para o crescimento econômico sustentável e a preservação dos recursos naturais para as gerações futuras.

Palavras-chave: digitalização, economia circular, setor agrícola, economia regional, desenvolvimento sustentável.

1. INTRODUCTION

The sustainable development of the agricultural sector is one of the critical challenges for the regions of Ukraine, where the agro-industrial complex plays a significant role in economic growth and ensuring food security. However, traditional methods of management during the war, the consequence of which is the degradation of land resources, as well as due to environmental pollution and depletion of natural resources, are becoming less and less effective, which increases the urgency of the transition to new business models. In this context, the concept of circular economy, which is aimed at closing the resource circle by minimising waste and reusing production resources, can become a critical tool for ensuring the agricultural sector`s sustainable development.

However, implementing the circular economy in the production processes of the agricultural sector requires the widespread use of digital technologies that ensure the effectiveness of monitoring, control and management of resources. Modern digitalisation tools, such as the Internet of Things, artificial intelligence, blockchain and big data, allow the optimisation of supply chains in the agricultural sector, reduce waste, ensure operations transparency and increase environmental responsibility. At the same time, currently in Ukraine, these technologies have yet to receive sufficient support and distribution, and their implementation in the agricultural sector faces several obstacles. Among the fundamental problems, it is necessary to note the need for a clear digitalisation strategy at the regional level, the lack of investment resources, and the insufficient technical training of most agricultural enterprises and personnel.

Thus, the issue of using the circular economy in combination with digital technologies to ensure the sustainable development of the agricultural sector of Ukraine is gaining particular relevance. Solving these tasks can reduce the environmental burden, increase the economic efficiency of production processes, and create a competitive and sustainable agro-industrial complex at the regional level.

2. LITERATURE REVIEW

The concept of circular economy has recently attracted considerable attention from scientists and practitioners as one of the key directions in ensuring the sustainable development of various sectors of the economy, in particular, the agro-industrial complex. Many studies highlight that the circular economy is particularly relevant to the agricultural industry, as it has the potential to generate significant volumes of organic and inorganic waste that can be recycled or reused.

A significant contribution to the development of circular economy principles for the agricultural sector was made in the studies of I. Arakelova (Arakelova et al., 2024), T. Kulinich (Kulinich et al., 2021; Kulinich et al., 2022), V. Sarioglo (Sarioglo et al., 2024) and A. Verzun (Verzun et al., 2023), which consider circular practices in the form of closed production systems and claim that circular models help to significantly reduce the ecological burden of agricultural enterprises on the environment. At the same time, these theoretical provisions must be adapted to the specific conditions of the Ukrainian agricultural sector, where the circular economy is a relatively new and insufficiently researched approach.

Modern digital technologies, such as the Internet of Things, big data, blockchain and artificial intelligence, open new opportunities for introducing circular models in the agricultural sector. At the same time, the researches of I. Britchenko (Britchenko, 2023; Britchenko et al., 2021; Britchenko et al., 2022), T. Shmatkovska (Shmatkovska et al., 2022a; Shmatkovska et al., 2022b; Shmatkovska et al., 2023), and A. Zielińska (Zielińska et al., 2018) determine the critical role of the Internet of Things in ensuring the sustainability of agricultural enterprises by monitoring resources and predicting optimal conditions for agricultural production. At the

same time, the possibilities of using sensor networks to manage water resources and fertilisers are noted, which allows for an increase in the efficiency and environmental friendliness of production processes. The research also notes that artificial intelligence helps optimise agricultural producers` logistics chains, which is especially important for reducing waste and product losses during storage and transportation.

At the same time, the research of M. Dziamulych (Dziamulych et al., 2022; Dziamulych et al., 2023), V. Kostiuk (Kostiuk et al., 2024), O. Polishchuk (Polishchuk et al., 2022), R. Sodoma (Sodoma et al., 2022) and others. Confirm that implementing blockchain technologies can significantly increase trust between market participants, ensuring the tracking of each stage of product movement and verifying ecological approaches in agricultural production. In addition, the researchers say that an integral element of the application of blockchain technologies is big data, which is used to analyse the behaviour of consumers and suppliers, which allows adapting production cycles to demand better and avoid overproduction, which is one of the sources of waste.

In general, there are many scientific developments in the agricultural sector`s digitalisation field based on ensuring its sustainable development. However, researchers rarely consider the issue of combining the circular economy with digitisation in the farming sector as a driver of its sustainable development, which requires further research in this direction.

3. METHODOLOGY

To achieve the research goal, a complex of specialised methods of scientific knowledge of the issues of digitisation and circular economy in the agricultural sector of Ukraine was applied. The basis of the research is a combination of theoretical and empirical approaches that allow you to investigate issues from different angles and provide a comprehensive analysis of the impact of digital technologies on the development of the agro-industrial complex.

The abstract method was used to evaluate a generalised model of the transition of the agricultural sector to a circular economy using digital technologies. Based on the theoretical justification of the circular economy and the study of the world experience of introducing digital innovations in the agricultural sphere, an abstract model was defined that demonstrates the main components of the process, which include resource recycling, energy efficiency and optimisation of logistics of farm enterprises. Abstraction also made it possible to single out essential aspects of sustainable development, which is the basis for further empirical analysis of this issue.

The application of the monographic method consisted in the study of individual cases and regional programs based on the principles of the circular economy and using digital technologies in the agricultural sector. This method made it possible to reveal the specifics of the implementation of the circular model and determine the main obstacles and prospects for the regional agricultural industry of Ukraine. Within the framework of the method, the experience of European countries was analysed in the context of its adaptation to Ukraine, particularly in the use of digital solutions to optimise the resources of agricultural enterprises.

The application of the method of logical generalisation consisted in combining data on the results of the implementation of circular and digital technologies in different regions, which made it possible to determine general trends, favourable factors and limitations of the development of the agricultural sector. Based on the analysis of data from different regions, regularities were determined that can be applied at the national policy level for the development of the agricultural sector of Ukraine. Also, this approach contributes to the adaptation of foreign experience. It makes it possible to scientifically substantiate recommendations for the effective digitisation of the agricultural sector to achieve the goals of sustainable development.

The correlation analysis method was used to assess the dynamics of investments in digital technologies based on the results of their implementation in the agricultural sector of Ukraine.

For this, the Pearson correlation coefficient was used to determine the relationship between investments in digital technologies (X) and the final results (Y):

$$r_{XY} = \frac{\sum(X_i - \overline{X})(Y_i - \overline{Y})}{\sqrt{\sum(X_i - \overline{X})^2 \sum(Y_i - \overline{Y})^2}}$$

where: Xi – value of investments in digital technologies for the i-th region,
Yi – value of investment efficiency for the i-th region,
X і Y – average values, respectively, for the corresponding indicators.

This correlation coefficient ranges from –1 to 1, where values close to 1 or –1 indicate a strong direct or inverse correlation, respectively. Values close to 0 indicate weak or no correlation between these indicators.

Also, the calculation of the linear regression dependence made it possible to estimate the extent to which the volume of investments affects the efficiency of sustainable development. The linear regression model, which describes the relationship between the amount of investment in digital technologies X and the indicator of sustainable development Y Y, was formed in the form:

$$Y = a + bX$$

where: a – free regression term;
b – regression coefficient showing the impact of changes in the volume of investments on the indicator of sustainable development.

In general, the applied research methods made it possible to obtain both theoretical and practical results, which provided a proper justification of the recommendations for the development of strategies for the sustainable development of the agricultural sector of Ukraine based on the circular economy and digitalization.

4. RESULTS

In the modern conditions of the functioning of the agricultural sector of Ukraine, which is characterised by economic instability and the destructive influence of Russian aggression, there is a need to ensure the sustainable development of regional agricultural systems aimed at preserving natural resources, reducing the environmental burden and increasing the overall efficiency of production. At the same time, the strategy for developing the agricultural sector must consider the challenges associated with the depletion of land resources and the need to ensure the country`s food security. In this regard, the circular economy concept becomes particularly important, as it promotes the transition from a linear model of resource use to a cyclical process where resources are stored and reused for the most extended possible period.

For the successful implementation of the circular economy in the agricultural sector, the wide application of digital technologies that control, monitor and optimise resources is objectively necessary. In this aspect, digitisation is a vital tool for achieving the goals of the circular economy, as it provides opportunities for automating business processes, decision-making based on big data analytics, and overall reduction of industry resource losses.

Digitisation of the agricultural sector significantly reduces production costs due to the optimisation of resource management processes, increasing the productivity and efficiency of management decisions. The basis of this approach is that using digital technologies allows enterprises to move from a traditional management model to one based on reliable data, ensuring maximum accuracy and reducing risks in production cycles. Accordingly,

implementing digital analytics systems allows forecasting based on statistical data and current market indicators, which helps avoid unnecessary costs of material resources and energy. Cost reduction in material and human resource management is also achieved by reducing unnecessary operations and automation, which increases labour productivity and minimises risks related to the human factor.

Also, digital innovations contribute to more efficient management of supply chains, allowing enterprises to obtain maximum transparency in the processes of transportation and storage of products. Transparency in supply chains based on digital platforms ensures the detection of possible delays and losses at early stages, allowing timely adjustments of logistics and production decisions. Through digital transformation, businesses can optimise risk management by using predictive models that will enable them to adjust strategies based on changing markets and natural conditions. Therefore, digitalisation creates an integrated information base for making informed management decisions aimed at reducing costs and increasing the profitability of production.

At the macroeconomic level, the digitalisation of the agricultural sector contributes to reducing the overall level of costs in the industry, as it ensures more efficient use of resources, reduces the need for physical labour, and reduces infrastructure maintenance costs. All these factors lead to the optimisation of costs not only at the level of an individual enterprise but also in the entire agro-industrial complex, increasing the overall economic efficiency of the industry.

It is worth noting that investments in digital technologies in the agricultural sector of Ukraine are critically crucial for increasing the productivity, sustainability and economic efficiency of the industry. Digital tools make it possible to optimise the use of resources, which reduces production costs and increases the profitability of enterprises. At the same time, the Ministry of Agrarian Policy of Ukraine emphasises that such investments increase the sector`s environmental sustainability, ensuring compliance with modern standards of ecological production and contributing to the sustainable development of agricultural territories (Ministry of Agrarian Policy and Food of Ukraine, 2024). Therefore, such investments not only strengthen the competitiveness of Ukrainian agricultural enterprises on the international market but also contribute to the development of digital infrastructure in the country, which is an essential factor in the economy`s growth.

During 2018-2023, investments of Ukrainian agricultural enterprises in digital technologies were constantly growing. At the same time, the most significant agricultural holdings, such as “Kernel”, “Myronivskyi Khliboprodukt”, and “Agroprosperis”, actively financed the implementation of digital innovations. In particular, during this period, “Kernel” invested about 10.7 million USD, and “Myronivsky Khliboprodukt” – about 7.5 million USD to improve production efficiency. These investments aimed to develop digital platforms for managing resources and monitoring production processes, which helped reduce costs and increase production productivity. In 2021-2022, investment activity in digital technologies remained significant.

Program support from international partners, such as USAID, has facilitated the implementation of digital infrastructure, especially for small and medium-sized enterprises. However, due to economic instability and hostilities in 2022, the total volume of capital investments in the agricultural sector decreased slightly. Still, larger companies continued to invest in automation, which helps to maintain competitiveness (Ministry of Agrarian Policy and Food of Ukraine, 2024). However, after the beginning of Russian aggression, agricultural enterprises reduced costs for digitalising business processes. To assess the dynamics and direction of capital investments in digital technologies, it is necessary to carry out their correlation assessment (Figure 1).

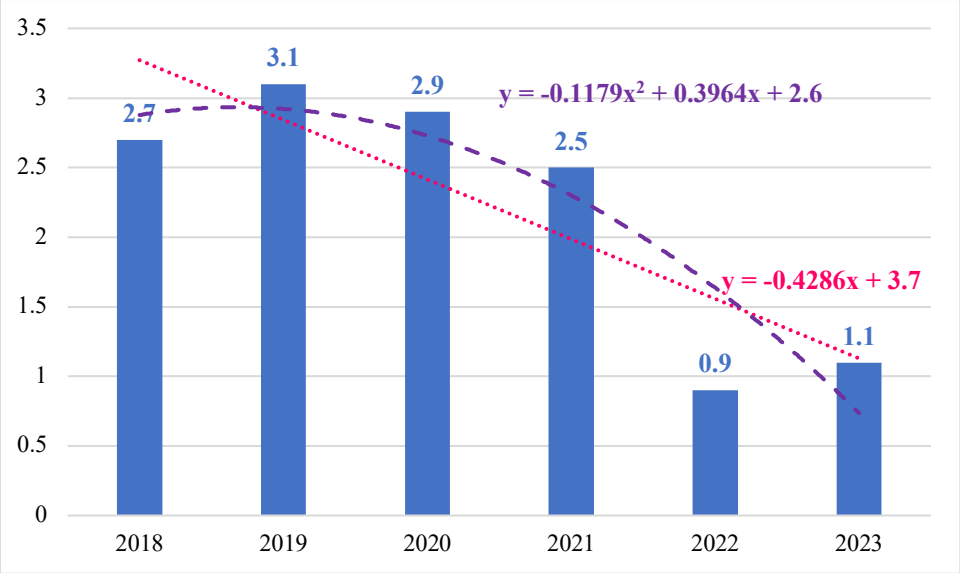

Figure 1. Correlation assessment of investments in digital technologies by agricultural enterprises of Ukraine for 2018-2023, billion USD. Source: calculated by the author on the basis of data (Ministry of Agrarian Policy and Food of Ukraine, 2024)

From the figure, we can see that the determined parameters of the linear trend show that the dynamics of investments during the analysed period had a clear tendency to decrease. At the same time, the absolute decrease of this indicator is determined to be 0.4286 billion USD. On the other hand, the analysis of the results of the polynomial trend shows that the actual annual change in the volume of investments in digital technologies is 0.3964 billion USD. for its initial reduction of USD 0.1179 billion.

According to analysts, a significant share of investments in the digitisation of the agricultural sector falls on precision agriculture and technologies of sustainable agriculture. Introducing drones for field processing and monitoring, as well as management technologies based on artificial intelligence, has become a vital tool for supporting the efficiency of the Ukrainian agricultural sector (Zhuk et al., 2024). At the same time, the increase in energy costs and the need to reduce the costs of fertilisers and plant protection products stimulate agricultural enterprises to implement real-time monitoring technologies, allowing them to minimise resource use and improve harvest quality (Latifundist, 2024).

In addition, according to official reports of the Ministry of Agrarian Policy and Food of Ukraine, investments in digital solutions are supported by international programs such as USAID AGRO, which promotes the development of digital infrastructure at the level of small and medium-sized agricultural enterprises. In particular, as of the end of 2022, a significant part of such programs was aimed at supporting innovations in agriculture related to the implementation of tools to reduce costs and increase the industry`s environmental sustainability (Ministry of Agrarian Policy and Food of Ukraine, 2024) At the same time, estimating the share of investments in digitalisation of the agricultural sector is necessary relative to the total amount of investments in the industry (Figure 2).

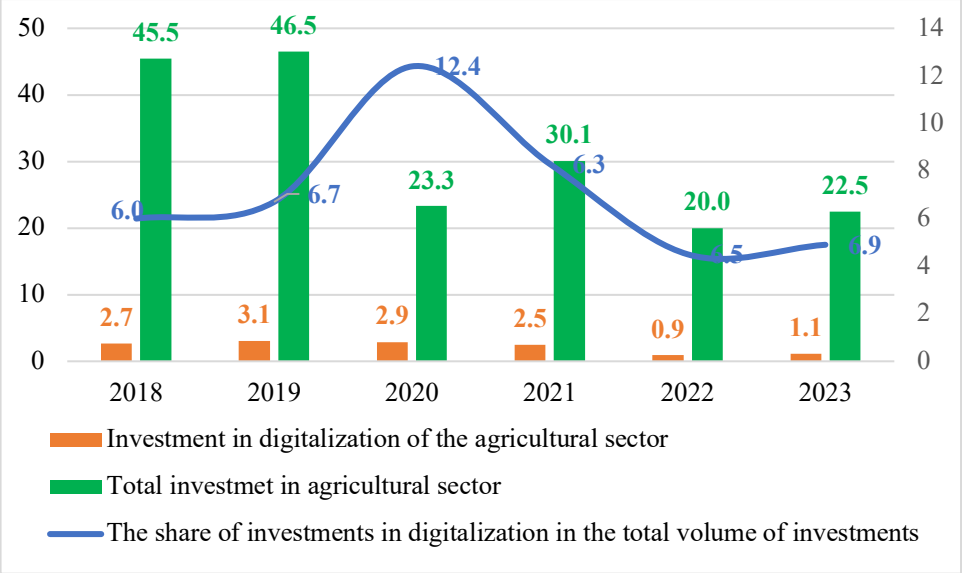

Figure 2. Dynamics of investments in the agricultural sector of Ukraine for 2018-2023, billion USD. Source: calculated by the author on the basis of data (Ministry of Agrarian Policy and Food of Ukraine, 2024)

As you can see, after the war, not only did the total volume of investments in the agricultural sector of Ukraine decrease, but the share of investments in its digitalisation also decreased. If in 2021 it was 8.3%, then in 2023 it decreased to 4.9%. At the same time, the highest value of this indicator was recorded in the conditions of the COVID-19 pandemic, when in 2020, investments in digitalisation of the agricultural sector of Ukraine amounted to 12.4% of all assets in the industry. The dependence of the volume of investments in digitisation on their overall dynamics will be determined based on a correlation estimate (Figure 3).

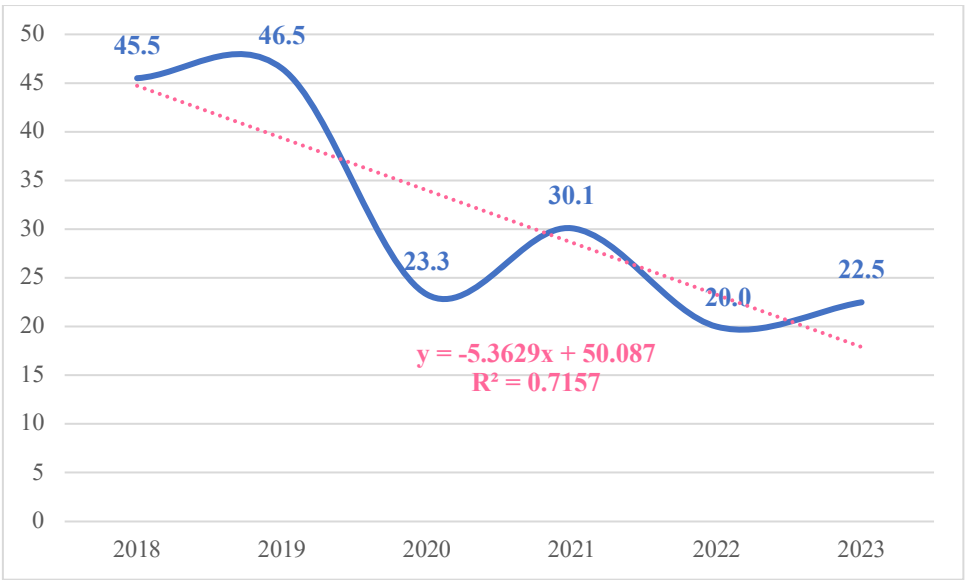

Figure 3. Correlation assessment of total investments in the agricultural sector of Ukraine for 2018-2023, billion USD. Source: calculated by the author on the basis of data (Ministry of Agrarian Policy and Food of Ukraine, 2024)

Therefore, it can be concluded that the dynamics of total investments in the agricultural industry of Ukraine during the analysed period were characterised by a tendency to decrease. At the same time, the average annual reduction rate was 5.3343 billion USD per year. Because

the value of the approximation coefficient in this case is not too close to 1, it can be concluded that the influence of this trend on investments in digitisation, although significant, could be more reliable. This means there are other reasons for changes in the volume of investments in the digitalisation of agricultural enterprises in addition to the general trend of farming investments.

For implementing a circular economy in the production and resource processes of the agricultural sector of Ukraine, two leading innovative solutions already used in enterprises` business processes are relevant: precision farming systems and digital platforms for waste and secondary resource management. Each of them is aimed at optimising the use of resources, reducing waste and improving management efficiency, which are the main principles of the circular economy.

Precision farming systems are the foundation for rational use of resources in the agricultural sector. They provide real-time control and management of crop growing conditions based on data analysis of soil, climatic conditions, humidity level, and other parameters. Precision agriculture technologies include using drones, satellite data, sensors and the Internet of Things (IoT) to provide accurate and localised data on the condition of fields. This allows farmers to apply fertilisers and plant protection products only when and where necessary, thereby reducing the costs and volumes of agrochemical use and preventing soil and water pollution. The implementation of precision agriculture as an innovative solution for the circular economy allows the creation of a more efficient model of resource management, which helps to minimise the use of available resources and is essential for reducing costs and protecting the environment. At the same time, as statistics show, the share of agricultural land cultivated with the help of precision farming systems in Ukraine is constantly growing (Figure 4).

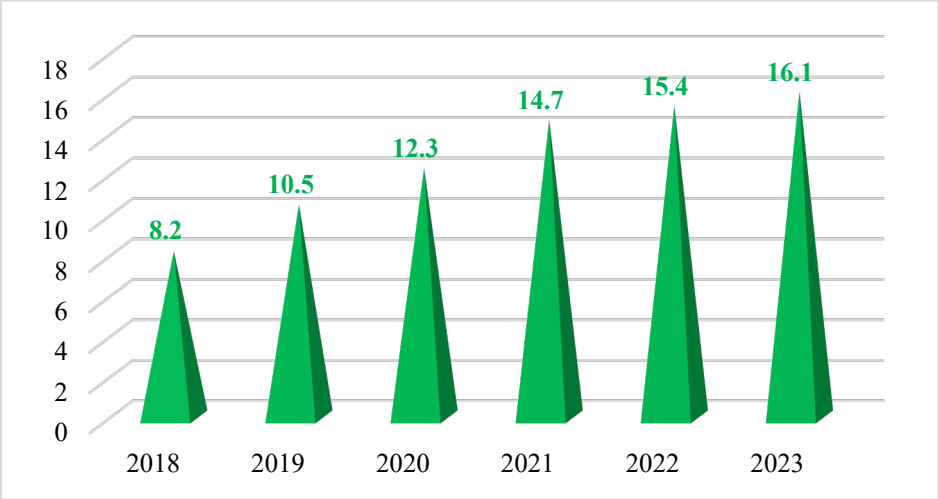

Figure 4. The share of land cultivated using precision farming systems in Ukraine for 2018-2023, %. Source: (Ministry of Agrarian Policy and Food of Ukraine, 2024)

In addition, precision farming allows for a significant waste reduction, as resources are used only in the necessary amount. This directly corresponds to the principles of the circular economy, where the main thing is the maximum preservation and reuse of resources. Therefore, effective management of agricultural resources with the help of precision agriculture allows for the reduction of product losses at the stages of cultivation, which reduces the risk of overproduction and excessive use of resources.

The use of digital platforms for managing waste and secondary resources, in turn, allows you to track and control all types of garbage that arise in the production process and ensure the integration of systems for utilisation, recycling and reuse of resources. Such digital platforms

create opportunities for planning and coordinating waste collection, storage and transportation processes based on modern technologies. With the help of such platforms, agricultural enterprises can, with blockchain technology, ensure transparency and security of data exchange about waste and its origin and disposal methods, which is essential for confirming compliance with environmental standards. This approach is particularly relevant in ensuring Ukraine`s compliance with EU standards. In this aspect, using blockchain in such platforms ensures the immutability and reliability of information that can be used to create "green certificates" and other documents confirming the ecological purity of products.

Thus, the introduction of precision agriculture and digital platforms for waste management are innovative solutions that allow the formation of a circular model in the production and resource processes of the agricultural sector of Ukraine. Thanks to these technologies, agricultural enterprises can significantly reduce resource costs, optimise waste management, and create closed cycles of material use, which contributes to the industry`s sustainable development and increases the competitiveness of the Ukrainian agro-industrial complex in the global market.

5. CONCLUSION

Therefore, integrating the principles of the circular economy and digital technologies into the agro-industrial complex of Ukraine opens up new prospects for its sustainable development and increasing competitiveness in the world market. Combining these two approaches allows for the creation of closed production cycles that efficiently use resources, reduce dependence on primary raw materials and minimise the negative impact on the environment. At the same time, the large-scale application of digital technologies makes it possible to quickly make decisions and adapt production processes to the changing conditions of the business environment, which not only reduces costs but also increases the quality of products and acts as an essential factor in competitiveness.

At the same time, the greening of agricultural production in Ukraine allows farmers to open new sales markets, especially in the European Union, where the requirements for environmental standards are high. Businesses that implement ecological approaches in their production processes, such as precision farming and reuse of resources, can obtain "green certificates", which increase consumer confidence and open promising opportunities for export. Therefore, the transition to a circular model not only helps to reduce costs but also ensures the stability of enterprises in conditions of instability of resources and prices for raw materials.

In general, implementing the circular economy in the agricultural sector of Ukraine with the support of digitalisation is a powerful driver for achieving economic sustainability, reducing the environmental burden and increasing resource use efficiency in modern conditions. After all, only enterprises that actively use innovative digital solutions can adapt to global trends of sustainable development and remain competitive and cost-effective at the international level.

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