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# Industry Specifics and Problems of Digitalization in the Agro-industrial Complex of the Republic of Kazakhstan

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**Abstract**
The purpose of this work is to analyze the effectiveness of management of the agro-industrial complex based on the introduction of digital and intelligent technologies that contribute to reducing the technological gap relative to the developed countries of the world, as well as stimulating the economic growth in Kazakhstan. The following methods were used in the study: information-logical, analysis and synthesis, systematization, economic modeling, and monitoring. As a result of the research, the difficulties, objective factors, and trends that determine the processes of agriculture in Kazakhstan were analyzed. It is given an economic assessment of the existing agro-industrial complex; it is established that an increase in the level of agricultural production depends on the need for new technical support and digital modernization. Based on the results of the SWOT analysis, it has been found that the environmental and economic conditions for the development of precision farming in the North Kazakhstan region require the government support that contributes to the development of new infrastructure. Practical solutions for digitalization processes of agro-industrial complex based on the high potential will lead to the creation of environmentally sustainable programmable farming and productive animal husbandry based on the advanced geospatial technologies, robotics, and artificial intelligence in general.

**Keywords** Digital transformation · Agriculture diversification · Profitability · Agri-food economy · Precision farming

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## Introduction

New information systems and digital technologies open up exceptional opportunities for agricultural management, and their implementation will allow aspects such as economic, social, and environmental ones not only within the state but also in a global sense. Enhancing the food security and the quality of population life is ensured by improving the management mechanisms and innovative activities of the agro-industrial complex (AIC) with subsequent transformation into modern high-tech industries of crop and livestock production. Smagulova et al. (2022) highlight that in Kazakhstan, the agro-industrial sector's growth is hindered by outdated technology and low investment. They suggest that adopting innovative digital solutions could optimize resource use and enhance productivity. Kazakhstan is working on establishing the conceptual and economic frameworks for modernizing agricultural production, focusing on structural upgrades, resource efficiency, high-tech methods, and expanding exports.

Due to limited adoption, digital tech hampers agricultural productivity. Kok et al. (2021) highlight digital transformation's potential in agribusiness, foreseeing 20–40% economic gains and new jobs. This systemic shift coordinates human, object, and institutional actions. Chukkapalli et al. (2020) in their works argue the practice of implementing the complex high-tech systems of artificial intelligence (AI) in agricultural management, by generating large amounts of data: Internet of Things (IoT), Global Positioning System (GPS), Geographic Information System (GIS), Earth Remote Sensing (ERS), Cyber Physical Systems (CPS), Unmanned Aerial Vehicle (UAV), and Big Data Analysis (BDA).

Digitalization plays a crucial role in diversifying agriculture, especially through precision farming technologies. Kadomtseva and Neifel'd (2021) emphasize the ability to manage agrotechnical processes at specific field locations through precise measurements. Precision farming, a subset of digital tech, encompasses equipment, software, and specialized machinery. These components optimize land use by monitoring vegetation development, creating indices for yield assessment, assessing soil fertility, generating electronic maps for tailored irrigation, and applying fertilizers and pesticides. However, challenges like poor rural internet connectivity, lack of skilled personnel, and absence of unified digital systems persist.

According to Balabanov et al. (2013), it is required that theoretical, methodological, and practical developments be made in relation to the development of agro-industrial complex, which are aimed at demonstrating and solving the promising target parameters of self-sufficiency in the main types of agricultural products and raw materials. Capital investments in digital technologies provide new forms of labor organization, service, and management, including the improvement of forms of control, accounting, methods of planning, and analysis. Buklagin (2021) notes that digitalization of plant growing increases grain yields by up to 25 centners per hectare, while the total costs are reduced by 20% in the first year. Livestock digitalization also reduces costs by 15–20% until the payback of new technical equipment, but its use on dairy farms leads to an increase in milk yield by more than 18%, the number of calves by 20%, and the total livestock by 10%.

The purpose of the study is to analyze the effectiveness of managing the agricultural complex using digital technologies, which will reduce the technological gap in the synthesis of global progress and will lead to sustainable economic growth of the Republic of Kazakhstan (RK).

## Literature Review

The Food and Agriculture Organization (FAO) (2022) predicts that the global population will reach 9.73 billion by 2050 and 11.2 billion by 2100. To support agricultural operations worldwide, FAO has developed various tools and platforms, including agricultural stress indices, a water quality portal, a data access and analysis system for land monitoring, a mobile app for agricultural events, tools for food price monitoring and analysis, and drone-based field monitoring systems.

In their study, Zhang et al. (2021) argue that agricultural producers must produce more food with fewer resources, utilizing robotics and artificial intelligence. They emphasize that digital transformation can create employment opportunities, mitigate rural isolation, and improve access to information, technology, and markets. Analyzing the prerequisites for the fourth industrial revolution's development and structure in 2011, Kupriyanovskiy et al. (2018) highlight its revival due to rapidly advancing technologies. This revolution has brought about significant changes in everyday life and the development of new working tools across industries. Prause et al. (2020) observe that digital transformation in agriculture transforms the digital, physical, and social realms through the adoption of new technologies.

The literature reviewed highlights the pivotal role of digitalization, particularly through technologies like AI, IoT, and GPS, in revolutionizing agriculture towards precision farming practices. Aubakirova and Isatayeva (2021) emphasize the formation of a complex digital ecosystem in agriculture, enabled by smart devices connected to the Internet of Things. This ecosystem comprises consortiums, technical partnerships, platforms, and clusters, which contribute to balancing the increasing global demand for agricultural products. Similarly, Bacco et al. (2019) and Polishchuk et al. (2020) advocate for the adoption of precision farming technologies driven by AI, IoT, and GPS. They stress the importance of spatial management enhancement to boost yields while minimizing the misuse of fertilizers and pesticides. The core idea is to optimize agricultural production for maximum profitability by reducing energy and resource wastage, thereby accelerating productivity growth.

However, there are gaps and contradictions that researchers aim to address. Firstly, while precision farming offers promising solutions for increasing productivity and sustainability, there may be challenges related to the accessibility and affordability of these technologies, particularly for small-scale farmers or those in remote areas. Additionally, the integration of digital solutions into agricultural practices requires adequate training and support for farmers to fully harness their benefits. Furthermore, the potential environmental impacts of widespread digitalization in agriculture, such as increased electronic waste or energy consumption, warrant careful consideration and mitigation strategies.

According to AlMetwally et al. (2020), internet technologies connect various remote devices such as robots, ground-based sensors, and drones. The data by Rijswijk et al. (2021) highlights the commercial potential of technological developments and start-ups in agriculture. The symbiotic relationship between these entities and larger companies enriches the landscape of agricultural innovation, promising advancements in efficiency and productivity. Cowie et al. (2020) emphasize the role of smart agriculture in addressing challenges related to crop cultivation, particularly in monitoring climatic factors like temperature and soil moisture. These insights contribute to improved decision-making processes for farmers, leading to enhanced agricultural outcomes. Zhangirova (2021) provides a positive evaluation of Big Data Analytics (BDA) platforms in agriculture, which offer detailed insights into various aspects such as rainfall patterns, water cycles, and fertilizer requirements. By leveraging such platforms, farmers can make informed decisions regarding planting, irrigation, and harvesting, ultimately boosting profitability and productivity.

However, there may be gaps in research regarding the scalability and accessibility of these technologies, especially for small-scale farmers or those in resource-constrained regions. Additionally, the integration of data from multiple sources and platforms for comprehensive decision-making might pose challenges related to data interoperability and privacy concerns. Addressing these gaps could further enhance the applicability and effectiveness of digital solutions in agriculture, ensuring their widespread adoption and impact.

Lopez-Morales et al. (2020) emphasize the importance of analytical information derived from fields and livestock, facilitated by agricultural robotics and mobile internet connectivity. This real-time data acquisition enables farmers to make informed decisions and optimize their operations. According to Tanha et al. (2020), satellite analytics indices have been developed, and their programs are calculated based on the generalized data on soil, variety, sowing time, agricultural technology, meteorological indicators and satellite maps, yield maps and formation technology, and seeding and fertilizer rates. These include Normalized Difference Vegetation Index (NDVI), Red-Edge Chlorophyll (ReCl), Normalized Difference Red Edge (NDRE), and Soil-Adjusted Vegetation Index (SAVI). Mohamed et al. (2021) discuss the emergence of digital platforms in agricultural commodity circulation chains, enabling efficient supply balancing and cost optimization through location tracking. This digitized approach enhances market responsiveness and streamlines logistical operations. Pogrebnaya et al. (2022) delve into the significance of artificial intelligence (AI) technology, particularly in analyzing big data for robotics applications in agriculture. AI-powered agro-robots perform various tasks like seedling inspection, weed detection, irrigation, pest control, and harvesting, contributing to increased automation and efficiency in crop production.

Researchers aim to address several gaps and contradictions in the realm of digital solutions in agriculture. While precision farming holds promise for enhancing productivity and sustainability, challenges related to the accessibility and affordability of these technologies persist, particularly for small-scale farmers or those in remote areas. Gaps in research exist regarding the scalability and accessibility of these technologies, especially for resource-constrained regions. The integration of data from multiple sources and platforms for comprehensive decision-making may also pose challenges related to data interoperability and privacy concerns. Addressing these gaps is crucial to enhance the applicability and effectiveness of digital solutions in agriculture, ensuring their widespread adoption and positive impact. To solve these problems, it is important to use a specific methodology that will effectively address these challenges and ensure the successful implementation of digital solutions in agriculture.

## Materials and Methods

Determining a quantitative assessment of the level of AIC digital transformation is one of the main tools for further improvement of agricultural production. The following general scientific research methods were used as a methodological basis: information-logical review of scientific and technical materials and the market for intelligent technologies for agricultural management, analysis and synthesis, systematization, economic modeling, and monitoring. To identify the AIC problems in the process of digitalization, it was used an information-logical method to study the digital and intellectual systems for assessing land resources, fixed assets, material resources, human resources, and forecasts for the development of agricultural sectors. There are several advantages to using the information-logic method to identify problems in agriculture in the process of digitalization. This method allows for the analysis of various systems and resources, such as land resources, fixed assets, material resources, and human resources. It helps to identify problems in these areas and establish their relationship with the digitalization process. The information and logic method helps to systematize and analyze a large amount of data from various sources, which allows for a comprehensive assessment of the situation in the agro-industrial complex. It helps to identify weaknesses and gaps that may arise as a result of the introduction of digital technologies, as well as to understand which aspects of agriculture need to be improved and supported for successful digital transformation. This approach allows us to consider the problem as a whole and provides a more objective assessment of the situation in the industry.

The following statistical and analytical data have been used: Strategy “Kazakhstan-2050”: a new political course of an established state and State Program “Digital Kazakhstan”—materials are devoted to the use of digital technologies in agricultural management. Within the framework of these state programs, it is planned to introduce digital solutions for AIC: information from digital sensors, mathematical models for analyzing processes from agricultural production to product marketing, chain modeling (creation—cost—production volume planning—product quality—profit), and systematizing mobile platforms (Message of the President…, 2012; Decree of the Government…, 2017).

The analysis and synthesis of the AIC production potential has become the main direction in the scientific and practical activities of digital transformation, as an object of forecasting and identifying key conditions that determine prospects for the development of technologies, improving the mathematical apparatus, and increasing the degree of qualitative certainty. Using the systematization method allows us to effectively organize and structure a large amount of information related to agriculture and digitalization processes. This method allows to carefully classify data according to various criteria, such as types of resources (land, material, human), forecast indicators, and types of tasks. This systematization makes information more accessible and understandable for further analysis and use. The systematization method also allows for the first assessment and analysis of the initial information, which is a key step in understanding the problems and needs of agriculture in the context of digital transformation. The formation of an initial database through systematization allows to identify the main trends, gaps, and opportunities, which helps to guide further research and development of digitalization strategies. This approach is effective for the initial stage of research, as it allows us to quickly get a general picture and identify areas for further work.

Digital transformation is aimed at improving the processes of formation and use of models for efficient farming in the implementation of specific management functions (planning, organization, regulation, optimization). According to the method of economic modeling, the calculation of improving the quality and the formation of SWOT methodology were conducted and used in the system of forecasting methods. The method of strategic planning has become a SWOT analysis, which consists of identifying factors of an organization, consisting of four categories: strengths, weaknesses, opportunities, and threats. The SWOT analysis conducted in this study aimed to assess the environmental and economic conditions of digitalization in the North Kazakhstan region within the context of agricultural production. This analysis identified several factors that contribute to the strengths, weaknesses, opportunities, and threats associated with the implementation of digital solutions in agriculture. SWOT analysis provides valuable insights into the current state and future prospects of digitalization in agriculture in the North Kazakhstan region. By understanding these factors, policymakers, researchers, and stakeholders can develop targeted strategies to promote sustainable and efficient agricultural development through digitalization. It used the method that considered the existing information base, the forecast period (short-term, medium-term, and long-term), goals and objectives, features, and conditions for the development of the production and economic potential of the agro-industrial complex of the Republic of Kazakhstan, in order to improve the quality and completeness of initial data used for the forecast calculations, assessment of phenomena and factors in the course of the digitalization process.

The monitoring focused on forecasting the production and economic potential of agricultural producers following the implementation of digitalization in the agricultural sector. This involved assessing the information technology capabilities within the digital economy that have been established. Tracking of the AIC objects for the purpose of foresight, based on the information platform of Big Data of the analysts Hassani et al. (2014), provides cloud access to big data processed using the digital transformation of various processes in agriculture. This platform provides high-speed processes for collecting, transmitting, storing, and processing information via the Internet of Things in the interests of its main users, agricultural producers. By leveraging these methodologies, the study aimed to generate meaningful results regarding the effectiveness and implications of digital solutions in agricultural management and production.

## Results

### Enhancing Agricultural Efficiency Through Digital Transformation

The world population has exceeded the mark of 8 billion people, so the food production should be more efficient and less costly. At the same time, the growing demand for agricultural products cannot be resolved by simple linear scaling, outdated transportation networks, uncontrolled management of water resources and electricity resources, and tightened environmental regulations. Modern business conditions are characterized by increased competition in world markets. Being in the era of digital globalization, the main data streams containing information about effective functioning, ideas, and innovations have already been identified; and in 2020, 25% of the world economy has switched to the introduction of digitalization technologies for the state, industries, business structures, and population. Digital technologies in Kazakhstan are the main way to diversify the national economy and industry with a gradual reorientation from the raw material to an industrial service model. Digital agriculture applies the latest technologies—sensors, robotics, and data analysis—to transfer from monotonous tasks to continuously automated processes. The modern agro-industrial complex depends on changes in global trends, such as population growth and urbanization, preferences for the consumption of quality food, changing climatic conditions, trade globalization, and the development of bio- and nanotechnologies. The agriculture evolution under the influence of industrial revolutions is shown the Table 1.

These are the information environments for adapting advanced digital solutions for agricultural producers: Dassault Systemes, Micromine, Wencomine, Sight Power, Microsoft, and Wonderware. The use of robotic systems that allow

**Table 1** Stages of technological revolution in AIC

| Stage names | Stage characteristics |
|---|---|
| Agriculture industry 1.0 (pre-industrial) | Sustainable nature management with the use of natural fertilizers and control over the pests and weeds |
| Agriculture industry 2.0 (industrial) | Mechanization and automation of AIC |
| Agriculture industry 3.0 (industrial-informational) | AIC informatization with elements of precision farming and productive animal husbandry, with extensive use of toxic and chemical substances (fertilizers, pesticides, premixes, and fodder additives) |
| Agriculture industry 4.0 (technotronic-biotechnological) | Automation and informatization of AIC production, in addition to IoT, GPS, GIS, ERS, and CPS existing in all areas of agricultural production. Use of nanotechnologies, biotechnologies, nanoenergetics, and molecular-cellular technology. Partial robotization and development of full implementation of AI |

Source: compiled by the authorsbased on Steinke et al. (2020)

controlling the consumption of fuel, water, electricity, and crops increases the efficiency of work in agriculture by 50–70% and increases crop yields by 1.5–2 times while reducing the cost of sowing crops up to 80%. The use of AIC digitalization in efficient farming, crop growing, fodder production, and animal husbandry cannot be done without new elements of control and automation. The elements of digitalization are given in detail in Table 2.

Agriculture is a complex sector of the economy, and it is highly dependent on the climate, so the optimization of global food security requires special attention. The Law of the Republic of Kazakhstan No. 229-IV "On Amendments and Additions to Certain Legislative Acts of the Republic of Kazakhstan on Food Security Issues" (2009) describes the mechanisms for strengthening the food security of the state with the introduction of digital technologies, employment, incomes of rural producers, increasing market stability, creating conditions for the efficient use of natural, and industrial and financial resources. The increase in measures of state support for improving the efficiency and competitiveness of the AIC fields was approved by Decree of the Government of the Republic of Kazakhstan No. 960 "On approval of the Concept for the development of the agro-industrial complex of the Republic of Kazakhstan for, 2021–2030" (2021). According to Kantarbayeva and Tlesova (2019), it is planned to allocate 4.9 trillion tenge million from the budget for the implementation of industry breakthrough developments and technological updates. As a result, farmers that use modern digital solutions in the agro-industrial complex will increase the level of domestic market saturation by up to 50% by 2025. Of the planned amount, it was allocated 1.8 trillion tenge or 21% for the purchase of equipment and machinery, 108.6 billion tenge or 2.2% for seed material, and 180 billion tenge or 3.7% for mineral fertilizers.

**Table 2** Application of digitalization in the agro-industrial complex

| Digitalization elements | The content of applied elements of digitalization |
|---|---|
| Application of IoT sensors | Sensors and smart devices are connected and controlled automatically throughout the entire agricultural production process, helping to respond to climate change by improving the microclimate in the greenhouse |
| Light emitting diode technology | Optimization of the growth process applied in developed countries with little agricultural land |
| Application of photovoltaic cells (solar power plants) | Efficient use of space reduces energy costs; most of the equipment in the farm enterprise is powered by solar energy and solar panels |
| The use of robots | Simplify the care of agricultural plants and animals, popular in the regions with large production |
| Application of drones and satellites | Monitor the current state of data collection about farms, thereby analyzing recommendations for an updated database for accurate farm management |
| Internet, mobile communication, and cloud | Improving the operational efficiency of financial and logistics technologies |

Source: compiled by the authors based on Rose et al. (2021)

In the agro-industrial complex, there is a huge economic potential, connecting more than 40% of the population of RK; therefore, the economic potential of other industries and the socio-economic situation as a whole depend on the development of the agricultural sector. The Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (2022) reports that the main production volume of the agricultural industry amounted to 2.37 trillion tenge for the first 7 months of 2022 (crop production—402.5 billion tenge, livestock production—1.96 trillion tenge). Kazakhstan is one of the largest producers and exporters of grain crops. In terms of flour export, the country occupies a leading position on the world market. At the same time, the processes of processing and selling products on the local and global markets require improvement. For example, it is processed only 2–3% of the total volume of vegetable and fruit growing produced in the Republic of Kazakhstan, which indicates a rather low share of processing of agricultural products. At the same time, attempts are being made to restrict the export of raw materials in order to develop enterprises for the processing of raw materials.

Based on the specialized databases of the Institute of Marketing and Sociological Research “Elim” (2022), it has been found that the share of AIC of the Republic of Kazakhstan accounts for more than 8% of gross domestic product, 15% of the labor force, and 4% of production assets. Investments in the fixed capital of agriculture, forestry, and fisheries amount to 599 billion tenge in January–September 2022, which is 7.5% more compared to January–September 2021. The main indicator of economic activity in the crop industry includes the analysis and planning of crop yields, according to predicted parameters (Tsybukh, 2023).

Kazakhstan’s commitment to implementing digital solutions in the agricultural sector is an example of a forward-thinking approach to addressing these challenges. The country’s strategic initiatives, including significant investments in modern equipment and technologies, are aimed at improving the efficiency and competitiveness of the agro-industrial complex. By introducing advanced technologies such as IoT sensors, robotics, drones, and cloud computing, Kazakhstan is positioning itself not only to increase domestic market saturation but also to strengthen its role in the global agricultural market. The success of digital agriculture will depend on constant innovation and adaptation to emerging technologies. The use of data-driven approaches and automation will optimize agricultural processes, reduce costs, and increase yields, thereby ensuring food security and economic stability. As digital agriculture evolves, a more sustainable, efficient, and sustainable food production system will be created to meet the needs of a growing and urbanizing global population.

## Case Study: North Kazakhstan Region

The fourth part of RK territory is characterized by steppe, semi-desert, and desert latitudes. According to official data from KazData (2022), the agricultural land of RK is more than 200 million hectares, but only 40% (96 million hectares) of the territory is used in circulation. Under adverse weather conditions, it is observed that there are fluctuations in yields, and with low technological equipment, industries at all production stages (including post-harvest processes) suffer huge losses. These are the main grain-producing regions: Akmola, Kostanay, and North Kazakhstan. In 2021, their enterprises have earned 272.8 billion tenge in the industry, which corresponds to 45.5% of the total investment in agriculture, forestry, and fisheries of the Republic of Kazakhstan.

According to Klebanovich et al. (2016), the total land area of the North Kazakhstan region (NKR) is 9.8 million hectares, of which 7.3 million hectares are agricultural. These are mainly arable lands (4.9 million hectares) and pastures (2.1 million hectares). NKR is considered one of the main agricultural regions of the country; it is located at the junction of forest-steppe and steppe natural zones with fertile soils; 96% of these soils are chernozemic soil. Advanced farms in NKR are as follows: "Zenchenko and Co" limited liability partnership (LLP), "Mambetov and Co" LLP, "Tukym" LLP, "Taiynsha-Astyk" LLP, "North Kazakhstan Experimental Station" LLP, "Atameken-Agro-Timiryazevo" LLP, "Atameken-Agro" LLP, and "Zholdasbay-Agro" LLP. In the farms, special attention is paid to the issue of rational use of agriculture. The success of agricultural workers in NKR is due to strong state support, effective management of AIC, the introduction of advanced agricultural technologies for growing crops, modernization and radical renewal of technology, and scientific achievements.

A total of 107 agricultural enterprises in the region use precision farming and its elements, 7 of them at the digital level, 4 at the advanced level, and 96 at the basic level. The basic category of precision farming has been implemented on an area of 1.6 million hectares. This is about the use of electronic field maps, GPS trackers, and fuel and lubricant consumption sensors. Digital farms occupy 326 thousand hectares (7.7% of cultivated land in the North Kazakhstan region). They use electronic field maps, soil analysis data using electronic pesticide cartograms, weather data, geobotanical maps of vegetation and weed, and GPS trackers. Three-tier digitization of fields is expensive ($1.5/hectare), but the work in this direction is only gaining intensity, and an increase in demand will later reduce its price. The technology of creating electronic maps of farms is also gradually being introduced in animal husbandry (Consolidated analytical report…, 2021).

The leading agricultural holding "Atameken-Agro" LLP, which promotes the agriculture digitalization in NKR, consists of 16 companies that specialize in crop production, animal husbandry, seed production, storage, and processing of grain crops. The net profit of "Atameken-Agro" LLP for 2021 amounted to 15.19 billion tenge. The company uses the following digital technologies: field monitoring with Geosys satellites, Agroplan planning system, Agrofact module for monitoring agricultural machinery, Grain Balance for tracking records of movement, storage and processing of grain, history from fields, chemical maps, weather changes, and adjustment by means of Agromap mobile application. Based on digital transformation, farmland productivity has doubled in 4 years (Atameken-Agro, 2022; Chechelashvili et al., 2023).

The use of digital technologies makes it possible to increase the productivity of each hectare of cultivated land, to program grain production with annual optimization of the sown areas of grain crops, and to increase productivity with the use of mineral fertilizers. In the North Kazakhstan region, "Geoscan-Kazakhstan"

LLP is engaged in geoinformation mapping. The company takes inventory of land, creates electronic maps of fields, and monitors equipment and the crops' state. In 2020, the company conducted aerial photography of agricultural enterprises in NKR on an area of 150 thousand hectares, as well as digitized data on 44.530 hectares using the ERS method. For the chemical treatment of crops of grain and oilseeds, automatic control systems and GPS navigation are used, which increase productivity by 14.6%, reduce specific energy costs by 8%, fuel consumption by 17%, and working reagents by 14.5%. The total cash costs are reduced by 9%, and the annual savings amount to 6562.6 thousand tenge. When harvesting wheat, GPS navigation systems with a cursor pointer are used, which increase productivity by 2.1%, reduce total cash costs by 3%, and reduce labor costs and specific fuel consumption by 1.4%; annual savings in cash costs amount to 233.4 thousand tenge (Geoscan-Kazakhstan, 2022).

Ainagulova and Kulikova (2019) in their work assess the development of animal husbandry in the Republic of Kazakhstan. Livestock accounts for 45% of agriculture in Kazakhstan of the total gross output. In total, there are 179.2 million hectares of pasture areas in the Republic of Kazakhstan, where 30 million tons of fodder units are produced annually, which provide food for 13 million heads of farm animals, but the effective use of green fodder requires digital transformation of fodder production. The unsystematic use of pasture lands leads to their degradation; therefore, it is necessary to use smart technologies for rational livestock breeding. The program of digital animal husbandry in the Republic of Kazakhstan is being effectively implemented, but the development of new technologies requires rethinking in the functioning of complex technological system "man–machine-animal," "North-Kazakhstan Experimental Station" LLP uses digital technologies "Lepestok" when breeding beef cattle. The main technologies of "North-Kazakhstan Experimental Station" LLP are divided into four clusters: navigation systems GIS, ERS; unmanned aerial vehicles that track livestock in pastures and touch sensors; IoT data control platforms; data analysis and adjustment, as well as accurate forecasting and the herd management strategy by means of AI. In Table 3, the environmental and economic feasibility of developing precision farming is demonstrated, which is carried out through SWOT analysis that is used to assess the phenomena and factors influencing the course of digitalization process.

Analyzing the use of digitalization elements and precision farming in the peasant farms of the North Kazakhstan region, it is too early to talk about an organized system, but the labor productivity has increased by an average of 25%. The main goal of agricultural production is to maintain and increase yield by means of improving soil fertility and resource-saving technologies in growing products adapted to the natural conditions of RK. Efficiency from the digitalization of the economy by 2025 will allow creating an added value of 1.7–2.2 trillion tenge. The process of economy digitalization is rapidly gaining momentum in most countries of the world. According to the Digital Evolution Index (2022), countries such as Norway, Sweden, and Switzerland are leading in the digital world ranking, while the top ten include the USA, Great Britain, Denmark, Finland, Singapore, South Korea, and China. The fragmentation of AIC information infrastructure necessitates the research of digital technologies in all agriculture sectors (Edgar & Kharazmi, 2023).

**Table 3** SWOT analysis of environmental and economic conditions of digitalization in the North Kazakhstan region

| Title | Characteristics of the components of SWOT analysis |
|---|---|
| Strengths | Large areas of fertile land with the highest potential for soil fertility are cultivated in the North Kazakhstan region, and there is also a high potential for energy and resource saving for the development of precision farming. Full digitization of cultivated lands by the presence of the first layer of geographical maps |
| Weaknesses | There are many fields in the region with small contours of forest-steppe agrolandscapes; high price costs are required to create electronic maps of fields. The heterogeneous nature of the relief of field plots with erosional anatomy, cultivated land. Poor paying capacity of peasant farms. Undeveloped service structure and the lack of dealers on the periphery for digitalization of agriculture, a monopoly in the field of digital services. Climate in this region |
| Opportunities | Sustainability of agriculture, smoothing the risk of non-yielding through insurance. Development of various forms of highly profitable agricultural activities, production, and export potential |
| Threats | A decrease in the level of labor productivity and competitiveness of the agro-industrial complex in the North Kazakhstan region, due to the depletion of soils by oilseeds, a sharp decrease in the productivity of agrocenoses |

Source: compiled by the authors based on (2021)

The North Kazakhstan region serves as an illustrious example for comprehending the significant impact of digital agriculture in improving productivity and sustainability. The region's extensive agricultural territory, known for its excellent chernozem soils, offers a solid basis for the implementation of sophisticated farming technology. Although harsh weather circumstances and limited technological equipment have historically caused large variations in crop output and losses, the implementation of precision farming and digitalization is starting to demonstrate encouraging outcomes. The implementation of digital technology in NKR has already had a considerable influence. Prominent agricultural firms such as "Atameken-Agro" LLP have achieved notable increases in productivity by utilizing satellite monitoring, GPS trackers, and advanced data management systems. The use of precision farming techniques in several agricultural settings, even at rudimentary stages, has enhanced productivity and decreased expenses. Nevertheless, the shift towards completely digitalized farms, despite the high cost, holds the potential for even more substantial advantages in terms of productivity and sustainability.

The region has advantages such as extensive fertile land and significant potential for energy and resource conservation. However, it also encounters challenges such as the expensive process of developing electronic field maps and the diverse characteristics of field plots. To fully unlock the promise of digital agriculture, it is essential to address these deficiencies by making strategic investments and providing policy support. The effective implementation of digital technologies in the agricultural sector of NKR not only enhances local productivity but also contributes to the broader economic objectives of Kazakhstan. These innovations enhance the efficiency and competitiveness of the agro-industrial complex, leading to stabilized socio-economic circumstances in rural regions, increased market stability, and sustained food production. Kazakhstan's participation in the continuing digital transformation in agriculture positions it as a formidable contender in the global market, in line with current worldwide trends.

## Navigating Challenges and Leveraging Strategic Opportunities

Some significant empirical findings shed light on concrete aspects of digitalization in agriculture, offering valuable insights for both readers and policymakers. The research identified various digitalization elements applied in the agro-industrial complex, including IoT sensors, LED technology, photovoltaic cells, robots, drones, satellites, and internet/mobile communication. These technologies play crucial roles in enhancing productivity, optimizing resource usage, and improving operational efficiency across different stages of agricultural production. The adoption of digital technologies in agriculture has led to significant improvements in productivity and efficiency. For instance, the use of robotic systems has increased work efficiency by 50–70% and crop yields by 1.5–2 times, while reducing sowing costs by up to 80%. Precision farming techniques, enabled by IoT sensors and other digital tools, have resulted in more accurate and responsive agricultural practices, leading to higher yields and resource savings.

The study highlighted the importance of state support and investment in promoting digitalization in agriculture. Laws and government initiatives aimed at enhancing food security, such as the introduction of digital technologies and financial support for technological updates, play a crucial role in driving the adoption of digital solutions among agricultural producers. The research demonstrated the economic impact of digitalization in agriculture, particularly in terms of market saturation and domestic production levels. Farmers adopting modern digital solutions are projected to increase the level of domestic market saturation up to 50% by 2025, thereby reducing dependency on imports and enhancing food security. The study provided insights from regional case studies, particularly focusing on the North Kazakhstan region. It highlighted successful examples of agricultural enterprises and holdings leveraging digital technologies to improve productivity, enhance management efficiency, and achieve sustainable growth.

The importance of digital transformation in Kazakhstan's agriculture, especially in the North Kazakhstan region, was emphasized. The advantages of digital technologies in improving productivity and product quality are emphasized. The conclusions point to the need for joint efforts to integrate digital solutions into agriculture. It is also necessary to expand access to digital resources for farmers and industry workers. Continued research and development of customized digital solutions is also important. Implementing digital transformation is a strategic imperative for the competitiveness of Kazakhstan's agriculture. The study provides an important contribution to understanding the prospects for digital transformation in the agricultural sector, particularly in the North Kazakhstan region. It highlights the real impact of digital technologies on increasing productivity, optimizing production, and improving the quality of agricultural products. For future research, it is recommended to expand the scope of the analysis to include a wider range of agricultural enterprises and regions, as well as to take into account the impact of cultural and socio-economic factors on the process of digital transformation in the agricultural sector.

## Discussion

The agriculture of the Republic of Kazakhstan is a complex sector of the economy, and it is highly dependent on the climate, so the optimization of global food security requires special attention and an increase in the state support measures in order to increase the efficiency and competitiveness of the agro-industrial complex. The AIC digitalization makes it possible to reduce risks and adapt to all kinds of changes, increasing crop yields and animal productivity. The developed countries of the world continue to successfully modernize their economies at an accelerated pace, so they are introducing innovative digital technologies into agriculture: automation, computerization, and digital platforms, and soon artificial intelligence will control the work of the agro-industrial complex. Research developments of new agricultural robots, the production of which has increased significantly over the period 2010–2021, allow efficiently performing the difficult field tasks. The global pace of innovation has accelerated, but the agriculture of the Republic of Kazakhstan is still at the early stages of using digital technologies, despite the State Program "Digital Kazakhstan" that has been formed. In addition, according to the scientific data and methods of the relevant ministries, the developed integral indicators and expert assessments of RK agricultural economy are little specified (Message of the President…, 2012).

More than a third of the lands in the Republic of Kazakhstan are subject to degradation, but with the use of digitally modernized systems and the daily assessment of pasture lands with the use of algorithmic analysis, access to timely digital information on the state of crops will be available. The data will help agronomists make the best decisions with the highest productivity while using mobile sensor systems for assessing and analyzing the state of agricultural plants and animals under the changing conditions of the environment in the Republic of Kazakhstan. Based on the projects launched by "Geoscan-Kazakhstan" LLP, the integration of satellite analytics is gradually being conducted, which increases the existing value of precision farming applications (Geoscan-Kazakhstan, 2022). Asadov and Suleymanova (2022) note that the use of vegetation indices NDVI, ReCl, and NDRE in software provides suppliers with the following business management benefits: qualitative assessment of data, expansion of the range of services provided, access to the satellite geosources, reduction of internal costs of agricultural enterprises, and improvement of the quality of the products produced (Pashkov & Mazhitova, 2021; Shahini, 2024).

The formation of information support and the transparency of information flows, as well as the development of agriculture with an appropriate focus on the digital economy, are important directions in the development of agriculture in the Republic of Kazakhstan. The growth of literacy, professionalism, and creative thinking of agricultural workers in the field of information and communication technologies is necessary. Nikonorova et al. (2021) report on the prospects of methods of artificial intelligence, which is just emerging in a digital system. At the initial stage, the agricultural education programs are saturated with modern zootechnical and agronomic disciplines, while new specializations will appear in the future (agricultural informatics, management of agricultural enterprise, operator of smart farm or greenhouse, engineering of agricultural drones).

Digital transformation effectively distributes costs, benefits, and responsibilities in the global system, and at the same time, it requires participants to act in relation to possible negative consequences. The process of digitalization is taking place gradually, with a decrease in the number of labor forces, but with an increase in the cost of production aimed at researching robotic methods used in agronomy: irrigation, processing and protection, weeding, and harvesting. For most of the leading European Union (EU) countries, China, the USA, Republic of Korea, and Japan, the AIC digitalization is a priority for increasing sustainability and ensuring food security (Kassa, 2023). Today, it is digitalization that determines the level of development of crop production in the developed countries, including the USA, Canada, Japan, Australia, and the EU countries. van der Burg et al. (2019) note the important role of AI in the management of information lifecycle and data processing. According to the confirmed market research, AI in agriculture has been valued at 4.9 trillion tenge in 2019, but according to forecasts, it will reach 617,394.26 million tenge by 2027. In addition, AI aims to detect crop diseases and pests' control, monitor soil conditions, and assist in operations. In turn, such an increase in efficiency will allow for increasing crop yields and reducing the need to expand the land use (Shahini & Shtal, 2023).

Kazakhstan has already implemented the projects of "smart" farms in various areas of animal husbandry (dairy, meat, poultry). Today, the dairy farm "Olzha Sadchikovskaya" LLP and the meat farm "Terra" LLP already operate in this way, using technologies for protecting animals from diseases, systems of sensors for physiological monitoring the animals' state, and a complex of robotic machines. These are the major manufacturers of high-tech equipment in the livestock sector: Afi kim, DeLaval, Farmers Edge, Farm Works, and Trimble Inc. Taneja et al. (2019) describe in their work the artificial intelligence system when processing data and transformation into information Connected Cow or GyuHo SaaS "walking cow," created by the Japanese IT Corporation Fujitsu. Based on this system, a special bracelet is put on the animal, which counts the steps taken throughout the day. The data on herd activity is sent to the cloud, analyzed, and transmitted to the farmer's smartphone or computer. Information is updated every hour; thus, the specialists adjust the time of feeding, milking, and sleep, and it also becomes possible to detect pathologies or diseases at the early stages of development in these farm animals. In addition to the positive aspects of "smart" livestock farms, there are some drawbacks: the high cost of implementing technologies, the need for constant and stable Internet and power grid, the constant monitoring and control of narrow-profile experts, as well as robotic systems that can cause stress for animals.

The frequency of dry periods in Kazakhstan is high, on average, 2 years out of five. When exploring modern digital farming, producers gather valuable information from fields, which has been previously ignored or used through the traditional methods. Jung et al. (2021) describe in their work that the number of smart farms in the USA is reaching critical mass—there are about 1871 cooperatives serving 1,890,057 farmers. Thus, it is necessary to include AI systems at the cooperative level. Therefore, advanced technologies and infrastructure, when included in the cooperative ecosystem, can bring huge benefits for the small farmers who support these independent cooperative entities.

Gollinger and Harrer-Puchner (2022) assess the AIC digitalization in Germany, which occupies a leading position in the European Union. Particular attention is paid to creating conditions for digital transformation, using the precision farming systems and smart farms, as well as the possibility of reducing the harmful impact on the environment through the minimal or precise use of fertilizers and pesticides. Nurmanbetova et al. (2021) describe the state program of smart farming in Ireland in 2014, where digital technologies are widely used for individual farmers (1900 farms participate in the program). They are provided with a number of government platforms to reduce costs and emissions, and as a result, each farm has saved an average of 5000 euros in 2018, due to a 10% reduction in fuel costs. Based on the example of the leading holdings of NKR, the digital transformation of AIC in the Republic of Kazakhstan will be resolved by updating equipment and other material resources with partial compensation of the state budget and the concentration of technical and financial resources of the development of seed production, agriculture, crop production, fodder production, and animal husbandry, based on scientific developments of the best world practices.

AIC digitalization is aimed at simplifying the process of agricultural production using the autonomous robotic agricultural facility designed to breed agricultural plants and animals in automatic mode with optimal human participation. In terms of prospects for digital transformation and smart agricultural systems, the introduction of intelligent systems will allow saving about 20–40% of working capital in comparison with traditional methods; lack of routine work; qualified jobs for engineers, technicians, and IT specialists; and experience of countries with a developed agrarian sector.

The study has its limitations. In particular, it may not take into account some contextual factors, such as the cultural and institutional characteristics of the region, which may also affect the success of digital initiatives. In addition, the study may be limited in its geographic scope, and the results may not be fully representative of other regions or countries.

## Conclusions

Based on the study results, it can be concluded that Kazakhstan is a major producer and exporter of grain crops, but the processes of growing, processing, and marketing products still need to be improved. In particular, the agriculture digitalization in North Kazakhstan region is limited by the financial and technical possibilities for small and medium-sized entrepreneurs. Currently, 48% of arable land is cultivated in the North Kazakhstan region with elements of precision farming, providing an increase in the yield of cultivated crops (cereals, leguminous crops, and oilseeds) with a reduction in energy and resource costs. It has been established that the area of North Kazakhstan region land is 9.8 million hectares, while 7.3 million hectares are for agricultural purposes; this amount of cultivated land is due to strong state support. The most effective incentive for agricultural companies is considered the active introduction of precision farming systems at a basic level, and subsequently, the transition to managing smart farms. Summing up the results of the analysis, it can be noted that the North Kazakhstan region already uses the new digital technologies by the leading agricultural holdings that use such systems as Geosys, Agroplan, Agrofact, and Grain Balance Agromap. Innovative drones and the technical knowledge of assessing projects with vegetation indexes improve agricultural activity according to the advanced methods of harvesting, soil conditions, reporting on crop quantities, animals' physiological state and health, and damage assessment due to negative factors.

It has been revealed that a qualified transfer of the agro-industrial complex to software will give freedom in the decision-making process for the effective management of agricultural enterprises using programs and online platforms (Big Data analytics, robotic farms). The latest digital platforms will unite all AIC areas: calculate and track costs, manage seasonal workers, analyze the profitability of each individual crop, monitor the quantitative and qualitative analysis of agricultural products, modernize methods for raw material processing, produce animal fodder, and evaluate profitability and economic efficiency of production. Summarizing the results, it is possible to say that training of specialists who own both software and hardware digitalization tools is one of the main tasks of AIC diversification. Based on the foregoing, it can be concluded that AIC competitiveness depends on the effective use of digital diversification, rather than an increase in cultivated areas or the number of livestock. The successful development of the agro-industrial complex will reduce poverty, the gap with rural areas, and help provide access to information, new technologies, and world markets.

**Data Availability** The authors confirm that the data supporting the findings of this study are available in the article.

## Declarations

**Conflict of Interest** The authors declare no competing interests.

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