The object of the study is the digitalization of enterprises in the field of crop production to increase production efficiency. The problem of assessing the level of digitalization of enterprises in the crop industry and the effectiveness of implementing an industry-specific regional digital platform has been solved.

The results of the study were obtained:

– the analysis showed the absence of companies with an active level of digitalization, while a third (29%) have a stagnant level;

– the implementation of the digital platform provides a return on investment of 25.2%;

– a positive dependence of the revenue growth potential on the ADA integral score ($\beta_1 = 0.327$, $p = 0.002$) was revealed;

– the analysis showed a payback period of 0.80 years in a realistic scenario;

– in the cost structure for the implementation of the digital platform, the majority (43.2%) is allocated to the technical infrastructure.

The results of the study are explained by the use of the ADA model, which allows a comprehensive assessment of the level of digitalization of crop production enterprises, taking into account industry and regional specifics. The specifics of the results obtained are that this paper offers not only an assessment of the current state of digitalization, but also practical recommendations for the implementation of a digital platform adapted to the needs of the region.

The practical significance of the study lies in the proposal of a specific methodology for assessing the level of digitalization of crop production enterprises. In addition, the implementation of the digital platform will create a unified information environment for all market participants, reduce costs, optimize production processes and improve interaction between stakeholders. The results of the study can be used by government agencies, agricultural enterprises and developers of digital solutions for agriculture

Keywords: digitalization of agriculture, crop production, digital platform, economic effect

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ASSESSING THE POTENTIAL FOR IMPROVING PRODUCTION EFFICIENCY THROUGH DIGITALIZATION BY IMPLEMENTING A SPECIALIZED INDUSTRY DIGITAL PLATFORM

Botagoz Duissenbayeva
Candidate of Economic Sciences, Associate Professor*
ORCID: https://orcid.org/0000-0001-5959-7946

Raushan Gabdualiyeva
Doctor of Economic Sciences, Professor
Institute of Digital Economy and Sustainable Development
Zhangir Khan University
Zhangir Khan str., 51, Uralsk, Republic of Kazakhstan, 090009
ORCID: https://orcid.org/0000-0001-6354-1742

Gulnar Kunurkulzhayeva
Candidate of Economic Sciences, Associate Professor*
ORCID: https://orcid.org/0000-0002-0042-7341

Zhaxat Kenzhin
PhD Doctor, Professor
Department of Management and Innovation in Sports
Kazakh National University of Sports
Mangilik El ave., B 2.2, Astana, Republic of Kazakhstan, 010000
ORCID: https://orcid.org/0000-0001-6085-8349

Aisulu Parmanasova
PhD Doctor, Associate Professor
Department of Economics
Kyrgyz National University named after Zhusup Balasagyn
Frunze str., 547, Bishkek, Republic of Kyrgyzstan, 720033
ORCID ID: https://orcid.org/0000-0002-5885-0812

Yerlan Onlassynov
Corresponding author
Candidate of Agricultural Sciences
Department of Economics
Central Asian Innovation University
Madeli Kozha str., 137, Shymkent, Republic of Kazakhstan,160000
E-mail: erlan72@gmail.com
ORCID: https://orcid.org/0000-0001-5206-3095

Shynar Nurgaliyeva
Master of Economic Sciences, Senior Lecturer*
ORCID: https://orcid.org/0000-0002-3260-1666

Almagul Ibrasheva
Master of Economic Sciences, Senior Lecturer*
ORCID: https://orcid.org/0000-0002-6998-762X

Gaukhar Kairliyeva
Candidate of Economic Sciences, Professor
Department of Economics and Management
Kazakhstan University of Innovative and Telecommunication Systems
M. Mametova str., 81, Uralsk, Republic of Kazakhstan, 090006
ORCID: https://orcid.org/0000-0002-8572-7908

Wasiu Abiodun Sanyaolu
PhD Doctor, Senior Lecture
Department of Accounting
Crescent University Abeokuta
Ayetoro Road, 5, Lafenwa, Abeokuta, Ogun State, Nigeria, 111105
ORCID: https://orcid.org/0000-0002-0695-1961

*Department of Economics and Management
K. Zhubanov Aktobe Regional University
Aliya Moldagulova ave., 34, Aktobe, Republic of Kazakhstan, 030000

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1. Introduction

Production and economic systems in many countries are being transformed and modernized in the context of globalization. The leading modern international trend is digitalization, which acts as the primary direction of innovative transformations in all spheres of economic activity. Noonomics is coming to the fore in the form of a model of balanced economic, technological and social development, which includes digital developments that generate a new technological order.

Food security and sustainability of any country is always linked to the development of the agro-industrial complex [1]. Food supply is necessary in any crisis, and is also in demand for export. Objective reality requires transformation in all branches of the agro-industrial complex, and for this it is necessary to introduce progressive forms, methods and technologies into production activities. Improving digitalization in agriculture requires updating and management tasks that need a systematic solution. Agriculture in the EU countries of the last decade has been based on geo-positioning, integrated management of the technical park, and precision farming. This makes it possible to increase yields, use land efficiently, optimize costs, and reduce the amount of fertilizers, chemicals, and seeds [2]. But developing countries are significantly lagging behind in this area, as the emphasis is not on technological development, but on government support.

Digitalization is an important condition for realizing the innovative potential of the agro-industrial complex and bringing it to a competitive level. It leads to the creation of a cyber-physical space through the introduction of electronic and digital devices, systems, tools and the establishment of electronic and communication interchange, which forms an integral interaction between the virtual and physical world, accelerates and optimizes processes.

The scientific literature uses the term "platform economy" [3] or "digital platform economy" [4], which refers to online platforms with ecosystems independent of specific companies. Digital platforms provide a wide range of tools useful to end consumers, businesses and intermediaries, improving the interaction of all market participants. Due to this, the business reduces the cost of IT development of new products and their promotion. The use of advanced digital services improves collaboration and communication in the relevant market sector. Their creation in developing countries would bring the crop industry, as the most susceptible to climate risks and financial crises, to a new level of development.

Digital platform can be defined as a communication system with a clear algorithm for interaction between all market participants and human resources (HR) of enterprises within a single information environment. Its implementation helps to reduce costs by using digital tools, certain technologies, or reorganizing business processes. The introduction of such platforms into traditional sectors causes innovative transformations, changes the structure of markets and stimulates increased competition.

Therefore, study on the assessment of the digital transformation level of crop production enterprises, as well as the feasibility and effectiveness of implementing a regional digital platform in this area, is relevant.

2. Literature review and problem statement

Digital transformation is a key driver of the economic development of the agro-industrial complex, radically changing traditional management paradigms and forming a new model of economic growth. This process is based on the integration of advanced technologies into the practice of agricultural enterprises, which leads to the emergence of an information and digital type of development. This type of development is transformed from an auxiliary element into a convergent infrastructure, which is a fundamental condition for realizing the innovative potential of the industry. The ultimate goal of a smart agro-industrial complex is to achieve the highest possible level of automation, the key elements of which are:

1) databases and big data for analytical decision support;

2) smart technology and robotics (drones, autonomous systems);

3) analytical platforms for forecasting;

4) digital monitoring systems and product sales.

The analysis of the work [5] suggests an integrated approach of the authors to the systematization of the problems of modern agriculture. However, in the proposed digital solutions, the feedback mechanism between the introduced precision farming technologies and the long-term socio-economic effects for small businesses has not been sufficiently developed. However, the transfer of the proposed solutions to the soil of the agro-industrial complex of developing countries with the dominance of small and medium-sized enterprises may have a different effect.

The study [6] contributes to the development of the methodology of modeling agroecological processes due to the universality of the proposed PPS approach. However, the illustration of its applicability using the example of aquaculture and agroforestry leaves open the question of scalability to more complex multicultural agroecosystems with nonlinear dynamics. At the same time, the universality of the PPS approach, declared by the authors, raises doubts in relation to different regions. Thus, the scalability of the model for multicultural crop rotations remains open, especially in the context of the nonlinear dynamics of Kazakhstan's dry periods.

The article [7] proposes original spatial analytics for crop logistics. It is critically important that the authors do not consider the influence of institutional factors such as land rights or the specifics of cooperation between potato producers, which in real conditions can significantly modify the optimal logistics routes identified by purely spatial algorithms. However, the spatial analysis of the authors of this study does not take into account the specifics of land relations and cooperative relations in developing countries, where the role of personal subsidiary farms and rural areas is great. In real-world conditions, logistics routes are often determined not only by the geometry of fields, but also by informal agreements between manufacturers, as well as seasonal restrictions on transportation.

The implementation of these technologies is implemented in two main strategic directions: increasing overall productivity and reducing losses at all stages of the value chain.

Empirical evidence confirms that digital innovations in agribusiness contribute to a significant reduction in operating costs, increased productivity, increased output, and optimized use of all categories of resources – financial, labor, material, and land [8]. These solutions become particularly relevant in the context of overcoming the high losses typical of extensive agricultural production models, where up to 80% of products can be irretrievably lost at the stages of cultivation, processing, storage and logistics [9]. A qualitative leap in solving this problem is provided by the Internet of Things (IoT) technologies, which create a single digital ecosystem for interconnected objects. IoT finds applications in precision farming, smart greenhouse management, logistics control, and storage conditions. At the same time, for the system digitalization of the industry, it is critically important that IoT solutions are used by at least 70% of enterprises [10]. Specific optimization tools are GPS modules for monitoring transport, which allow for competent logistical planning to reduce fuel consumption by up to 20% [11], as well as specialized sensors and software for monitoring weight, temperature, humidity and gas composition in storage facilities, which minimizes the risks of theft and product damage and helps in making operational decisions. about its sale or processing [12]. At the same time, automation in smart greenhouses leads to significant savings in water, chemicals and fertilizers, while reducing human resource costs and minimizing errors caused by the human factor [13].

The countries from which some of the above empirical data were obtained – Ukraine, India, and Thailand – demonstrate a number of structural similarities with Kazakhstan, making their experience relevant for many emerging economies. All these states are among the large agricultural producers with a predominance of crop specialization and a significant proportion of small-scale farming in rural areas. Moreover, each of them faced the need for digital modernization with limited investment resources and uneven development of telecommunications infrastructure. Therefore, IoT solutions for precision farming, logistics control and storage management, which have been tested in these countries, can serve as a valuable starting point for adaptation in the Kazakh agro-industrial complex, especially in terms of reducing losses and optimizing resources.

However, the true effectiveness of digital technologies (DT) is revealed not by their disparate application, but by integration into a single economic and information space of the industry. This principle underlies the concept of "digital agriculture", the main idea of which is to create an integrated digital management platform. This approach is consistent with the trend of the platform economy, defined as a modern form of doing business in real time through digital intermediaries that provide a space for interaction between independent suppliers and consumers [14]. The platforms are characterized by four key features: direct contact between the customer and the supplier, free choice of operating mode for performers, post-payment for services or goods, as well as conducting all financial transactions through the platform's system itself, which together increases the efficiency and transparency of market relations. This theoretical model can be considered as a methodologically sound basis for the development of industry-specific digital platforms in regional crop production without the need to borrow foreign cases.

The article [15] rightly points out the key problem for the development of digital agriculture – the isolation of data received from satellites, drones and ground-based sensors. The proposed reference architecture of the digital platform remains at the level of a technical specification without working out business models that could ensure its commercial sustainability. The proposed reference architecture of the digital platform does not provide an answer to the key question for developing regions: which business models will ensure its commercial sustainability in conditions of relatively low rural density and/or low purchasing power of some farmers.

The study [16] introduces the conceptual framework and tools of business continuity management into agricultural issues, which is theoretically valuable. The use of multidimensional business intelligence schemes combined with machine learning classifiers demonstrates the potential for predicting failures in agricultural processes. However, the empirical basis of the work does not include an assessment of the cost-effectiveness of implementing the proposed solution, which is important from the perspective of a production approach. Although the concept of business continuity management is theoretically interesting, its empirical basis does not include an estimate of the costs of its technological implementation for manufacturers, which is important for low-income countries.

The methodological basis of the study [17], based on an involved approach using focus groups, allows to identify real contradictions between the needs of farmers and market requirements in the process of digitalization. The conclusion about the need for constant reconfiguration of open innovation ecosystems reflects an understanding of the dynamic nature of interactions in the agri-food sector. However, the results obtained largely do not reflect objective data on the effectiveness of the proposed business models. The use of focus groups revealed contradictions between the needs of farmers and the requirements of the market, but in post-Soviet countries these contradictions may have a different nature, in particular, due to the high proportion of government subsidies and administrative barriers to entry into foreign markets.

The authors of paper [18] focus on assessing the macroeconomic effect of digitalization, considering it as a universal growth trajectory for the Indian agricultural sector. However, this approach obscures the differentiation of regions and categories of agricultural producers, whose initial conditions for digital transformation differ significantly. Nevertheless, the authors of the paper convincingly demonstrate that the digitalization of agriculture can serve as a universal trajectory of economic growth, which is especially valuable for countries with a large agricultural sector.

The study [19] makes an important contribution to understanding the structure of agents of digital transformation of agriculture, shifting the focus from demand analysis to the study of technology supply. The authors show that the key drivers are private firms, including both traditional resource providers and technology startups. The work captures the risk of strengthening the market power of large agribusiness structures, but does not offer tools for quantifying and monitoring its dynamics. The study captures the risk of increasing the market power of large agricultural structures in developed countries with digitalization, but does not offer tools for monitoring this process in relation to the transition economy.

The paper [20] proposes a systematic set of six requirements for smart farming platforms. However, the proposed platform approach is primarily technical and architectural in nature and does not take into account the economic effects of the transition of agricultural producers to unified data exchange standards. Before implementing such an architecture, it is necessary to evaluate the cost–benefit ratio at typical enterprises in the country.

Global practice demonstrates examples of successful digital platforms in the agricultural sector, for example, the French Agriconomie platform, which unites suppliers and consumers of means of production, or the American LocalAgro, focused on the needs of local players in the agri-food sector.

Agriconomie functions as a vertical marketplace for agroindustrial resources, where suppliers of fertilizers, seeds, plant protection products and spare parts interact directly with agricultural producers. The platform's revenue model is based primarily on commissions from each transaction, as well as premium subscriptions that provide access to analytics of price trends and consumer behavior. A significant part of the functionality is devoted to optimizing procurement procedures, there are modules for comparing logistics tariffs and automatically generating specifications. However, there are practically no services linked to the production cycle, as the platform was created as a tool to save on purchases. This is offset by the farmers themselves having their own digital tools. But for regions where agricultural enterprises are only at the initial level of digitalization, copying an exclusively trading architecture looks unjustified.

LocalAgro has chosen a different trajectory: here the emphasis is shifted towards building communications between geographically close counterparties – farmers, small processors and regional distribution networks. Monetization is based on three sources: paid placement for sellers, reputation verification tools (including elements of blockchain transaction registration) and optional supply insurance.

Comparing LocalAgro with Agriconomie, it is possible to identify a common pattern: both platforms solve the problems of exchange (goods, contacts, reputation), but almost do not affect the tasks of production in a particular industry. The platforms are equally applicable to dairy farms, grain farms, or greenhouses. This is not a problem for developed agricultural economies, since the basic level of digitalization of enterprises allows them to independently "complete" the missing production modules.

Thus, global examples of using the digital platform cover a large economic cluster, which is why there is a lack of narrow industry specialization. This creates a shortage of examples of platforms that are deeply adapted to the specifics of individual sub-sectors, such as crop production, taking into account its unique regional and technological features. The creation and operation of such a specialized platform should go hand in hand with increasing the level of digital development of crop production enterprises themselves, which will gradually include more and more participants in the ecosystem and expand its functionality. In this regard, there is a need for a periodic objective assessment of the level of digital development of industry enterprises, which is an important prerequisite for successful platformization.

The analysis of the literature reveals several key study gaps.

Firstly, despite the abundance of work on the digitalization of the agro-industrial complex as a whole, there is not enough study focused specifically on a comprehensive assessment of the digital development of crop production enterprises, taking into account all the specifics of this sector (including land resources, seasonality, and climate risks).

Secondly, existing assessment models are often fragmented, focusing on technological aspects, and do not offer a holistic methodological toolkit covering the innovative, managerial, and human resources components of digital transformation.

Thirdly, the scientific literature poorly reflects the relationship between the current level of digital development of an individual enterprise and its ability to effectively integrate into the industry's digital platform and benefit economically from it. Most of the studies is limited to stating facts or describing technologies, without moving on to the development and economic justification of integrated platform solutions adapted for a specific region and sub-sector.

All of this supports the argument that it is appropriate to conduct a study devoted to the introduction of a specialized industry digital platform, the architecture of which takes into account regional and sectoral peculiarities of crop production. Such a platform will provide a significant positive economic effect for agricultural enterprises in the region, and the magnitude of this effect positively correlates with the initial level of digital development of enterprises, estimated by an integrated model.

3. The aim and objectives of the study

The aim of this study is the assessing the potential for improving production efficiency through digitalization by implementing a specialized industry digital platform.

To achieve this aim, the following objectives are formulated:

– to assess the digital development of crop production enterprises (ADA-analysis);

– to evaluate the effectiveness of the digital platform;

– to conduct an econometric analysis of the dependence of economic potential on the level of digitalization;

– to develop scenario forecasts of the economic effect (pessimistic, realistic, optimistic) from the introduction of a digital platform for crop production enterprises;

– to evaluate the cost-effectiveness of the digital platform implementation project and formulate practical recommendations for stakeholders.

4. Materials and methods

The object of the study is the digitalization of enterprises in the field of crop production to increase production efficiency. For the analysis, 21 enterprises in the region of a developing country (the Republic of Kazakhstan, Akmola region) for the production of agricultural crops were selected, which account for 89% of the region's products.

Based on the identified gaps, the following hypothesis of the study is formulated: the introduction of a specialized industry digital platform, the architecture of which takes into account regional and sectoral peculiarities of crop production, will provide a significant positive economic effect for agricultural enterprises in the region, and the magnitude of this effect positively correlates with the initial level of digital development of enterprises, estimated by an integrated model.

In the course of the study, some necessary assumptions were made:

– government support for the introduction of digital platforms in the country's agricultural sector will maintain a stable development vector without sudden budget adjustments or foreign policy shocks;

– the pace of technological progress in the field of IoT and artificial intelligence will remain predictable, excluding radical breakthroughs or, conversely, slowdowns caused by resource constraints.

The following simplifications were also adopted:

– multilevel interactions between various digital tools and traditional technology have been reduced to aggregated indicators of economic returns, without a detailed analysis of transaction costs at each stage of integration;

– the forecast scenarios for the development of the crop production base were limited to key variables with the exclusion of secondary factors, such as local climatic variations or differences in personnel qualifications, which made it possible to build a cause-and-effect structure and ensure compact results.

The methodology of the study is based on the author's model of agro-digital analysis (ADA), which includes six blocks: innovation, digital technology, management, human resources, equipment and technology, as well as land resources. Each block is evaluated according to qualitative and quantitative indicators, which makes it possible to determine the level of digitalization of enterprises.

The work is based on a methodology that makes it possible to assess the readiness of agricultural enterprises to implement digitalization. The logic of the author [21] was used to develop our own agro-digital analysis (ADA) model, which, using a system of test indicators, determines the sustainability of an organization in terms of the productivity of digitalization. The model also makes it possible to qualitatively and quantitatively assess the state of crop production enterprises from the perspective of digital transformations.

The methodology contains several blocks (Table 1).

The purpose is to assess the level of digital development that a crop production company is currently at.

Qualitative parameters are calculated by obtaining a point score, identified during a survey of the company's specialists:

– 0 points – the company does not carry out innovative digital activities or there is no information about them;

– 0.5 points – partial implementation of measures or the absence of their systemic nature;

– 1 point – the events are fully present.

Next, quantitative parameters are analyzed that characterize the extent to which digital technologies (DT) have been implemented in the crop industry to which the company belongs. Each block under study contains interval boundaries established based on the principle of the golden ratio (Table 2).

The analytical potential of the blocks makes it possible to obtain a comprehensive assessment of the impact of digitalization on crop production, the level of digital transformation of the company, the degree of innovative activity of the enterprise, as well as to identify the digital level of crop subjects. The assessment system consists of quantitative and qualitative indicators, absolute and relative, general economic and sectoral. The heterogeneity of the calculated indicators ensures the reliability of the results.

When carrying out activities in the field of crop production, it is possible to apply the management cycle [22], which consists of four stages: planning, implementation, verification, and adjustment (Fig. 1).

At each stage of the management cycle in crop production, it is necessary to use digital platforms for communication and interaction, starting from the stages of assessing soil conditions, planning crops, coordinating the interaction of agricultural machinery and equipment, comparing planned and actual results, to the stage of adjustment, during which artificial intelligence capabilities are activated.

A set of modules is provided to each group of users of the platform: agricultural producers, employees of agricultural enterprises, government agencies, owners of land resources, suppliers and consumers.

The assessment methodology for determining the potential economic effect of using a digital platform in regional crop production includes several areas of analysis: setting the total cost of implementation, calculating revenue growth, adjusting indicators to account for risks, and calculating the final performance indicators. The assessment of the payback period (PP) and the profitability index (PI) were used as basic indicators. PP is defined as the period required to cover the initial cost of innovation through additional cash flows generated by the platform. PI is calculated as the ratio of the present value of future cash flows to the volume of initial investments.

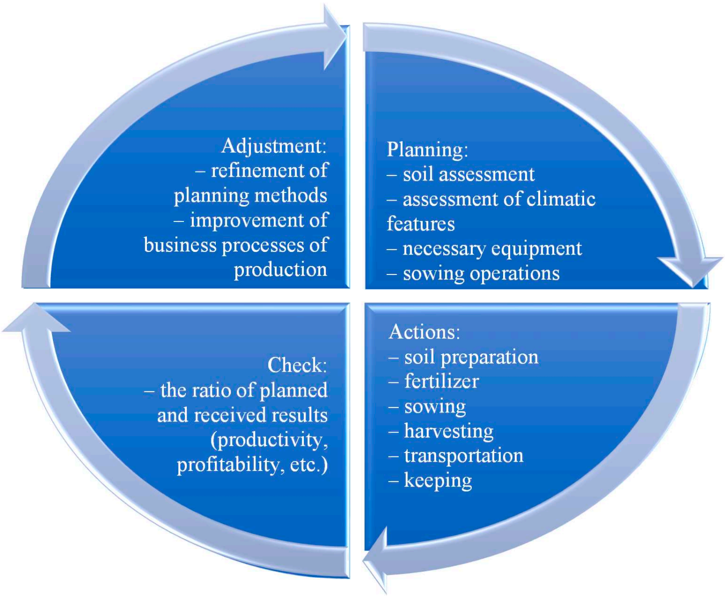

Fig. 1. The Deming-Shewhart cycle [22]

Table 1

ADA blocks

Block		Characteristic
IA	Innovative activity	Reflection of the developed and ready-to-use innovative means, methods, forms of marketing and management (M), the results of R&D in the field of «smart agriculture», genomic and breeding results
DT	Digital technologies	Assessment of the degree of digital activity
M	Management	Assessment of the effectiveness of the management decision-making system in terms of the use of digital technologies
HR	Human resources	Analysis of the human resource management system, the availability of digital competencies, and the implementation of activities to achieve or enhance them
E&T	Equipment and technologies	Assessment of the availability and availability of technical means and technologies necessary for the implementation of digitalization in agriculture
LR	Land resources	The study of land resources is a key object of digitalization

Note: Compiled from the source [21].

Table 2

Screening assessment of ADA analysis, determination of the type of digitalization

Block	Max, point	Threshold values			
		I active	II developing	III the starting	IV stagnant
IA	9.0	> 5.6	5.6–3.4	3.3–1.3	< 1.3
DT	9.0	> 5.6	5.6–3.4	3.1–1.3	< 1.3
M	6.0	> 3.7	3.7–2.3	2.2–0.8	< 0.8
HR	7.0	> 4.3	4.3–2.7	2.6–1.0	< 1.0
E&T	7.0	> 4.3	4.3–2.7	2.6–1.0	< 1.0
LR	9.0	> 5.6	5.6–3.4	3.3–1.3	< 1.3
Total	47	> 29.1	29.1–17.9	17.8–6.6	< 6.6

The modeling is based on the premise that the introduction of a digital platform that helps optimize innovation and production processes in crop production leads to lower direct costs and an increase in the speed and quality of product launch [23]. To take into account market uncertainty and different implementation trajectories, the impact assessment is carried out within the framework of three scenarios: pessimistic, realistic (basic) and optimistic.

The pessimistic scenario assumes a low rate of adaptation (coverage of 40% of target enterprises), conservative implementation of the platform's functionality and the preservation of high operational risks. The coefficient of realization of the potential effect (K) is assumed to be 0.6.

The realistic (baseline) scenario reflects the achievement of planned implementation targets (coverage of 70% of enterprises) and moderate user activity. In this scenario, $K = 1.0$, and calculations are based on detailed cost data and expected revenue growth.

The optimistic scenario simulates the conditions of active digitalization (covering 90% of enterprises), the full use of the platform's capabilities and the emergence of synergistic network effects. In this scenario, $K = 1.4$.

The final indicators of economic efficiency (income growth, PP, PI, return on investment) for the pessimistic and optimistic scenarios are calculated by applying the appropriate coefficient K to the baseline values obtained under the realistic scenario. This approach allows to obtain a range of possible results, assess the project's risk tolerance and determine the conditions for achieving maximum return on investment.

Table 3

The main economic characteristics of the enterprises studied (average data on the sample, 2024)

Indicator	Unit of measurement	The average value	Minimum value	Maximum value
Resource indicators				
Acreage	hectares	12.8	1.5	45.0
Average annual number of employees	people	124	25	400
Economic indicators				
Annual turnover (revenue)	million USD	8.4	0.7	22.5
The level of profitability of the main activity	%	15.2	1.5	32.0
Structural indicators				
The share of technology costs in total turnover	%	18.5	9.0	28.0
The share of crop production in the total turnover of the holding (where applicable)	%	94	85	100

Table 4

Scoring ADA analysis

No.	Company	IA 0–9	DT 0–9	M 0–6	HR 0–7	E&T 0–7	LR 0–9	Σ, point	Level
1	Atameken Agro	5.0	2.0	3.0	2.5	2.5	1.0	16.0	III
2	TNK Agricultural Company	3.5	2.0	2.5	1.5	0.5	1.0	11.0	III
3	Grain Consortium of Kazakhstan	3.0	1.5	2.5	1.0	0.5	0.5	9.0	III
4	Grain Logo	4.0	1.5	2.5	1.0	1.0	0.0	10.0	III
5	Sochi	3.0	1.0	2.0	1.0	0.0	1.0	8.0	III
6	Kusto Agro	6.5	4.0	3.5	3.0	2.0	3.0	22.0	II
7	Ascope	1.5	0.5	2.0	0.5	1.0	0.0	5.5	IV
8	Baumanskoe-2030	1.0	1.0	1.5	1.0	0.0	0.5	5.0	IV
9	Bastau	2.0	0.0	1.0	1.0	0.0	0.0	4.0	IV
10	En-Dala	0.5	0.0	1.5	1.0	0.0	0.0	3.0	IV
11	Zarechny	3.5	2.0	2.0	2.0	0.5	1.5	11.5	III
12	Agrofirma Rodina	5.0	3.0	3.0	2.5	2.0	4.5	20.0	II
13	Agrofirma Aktyk	4.5	4.5	3.0	2.5	1.5	2.5	18.5	II
14	Azat Agro	3.5	1.0	2.5	1.5	0.5	0.5	9.5	III
15	PZ Balkashinsky	4.5	2.0	2.5	2.0	1.5	1.5	15.0	III
16	Altyn Taga	6.0	3.5	3.5	2.0	2.5	2.0	19.5	II
17	Akmola-Phoenix	2.5	0.5	1.0	0.5	0.0	0.0	4.5	IV
18	Novokubanskoe	3.0	0.5	1.5	1.0	0.0	0.0	6.0	IV
19	Armavirsky	3.5	2.5	1.5	2.0	0.5	0.5	10.5	III
20	Ushakovo-Agro	3.0	1.0	2.0	2.0	1.0	1.0	10.0	III
21	NANAR Company	4.0	2.0	2.0	2.0	2.0	2.0	14.0	III

5. The results of the assessment of the level of digital development of crop production enterprises and the implementation of the regional digital platform

5. 1. Assessment of the digital development of crop production enterprises

Akmola region is one of the country's leaders in crop production, which makes it a representative region for studying trends in the agricultural sector. The study focused exclusively on activities related to crop production. The economic characteristics of the enterprises are presented in Table 3.

The level of profitability and cost structure are typical for a grain region with risky farming, which increases the value of the results obtained for the development of practical recommendations. Thus, the representativeness of the sample is ensured both by its dominant share in regional production and by its reflection of the key economic characteristics of the crop sector in the Akmola region.

The level of companies was calculated, showing the introduction of digitalization in the studied blocks (Table 4).

The result of the quantitative ADA analysis of 21 enterprises in the industry was the identification of an imbalance in the methods of digital modernization of various processes: administrative, managerial and production. The digital level of each enterprise under study was also compiled. No company has an active level of digital development and is absolutely stable in terms of the uses of digitalization.

The analysis of the state of the studied blocks of the digital level of development has been carried out, and thresholds have been used for this purpose. The standard is active > 62% of the maximum number of points of the studied block, developing ≥ 38% – < 62%, starting ≥ 14% – < 38%, stagnant < 1% (Table 5).

The calculated data is used to identify the most sought-after areas of development in the digital field of crop production in the region (Fig. 2).

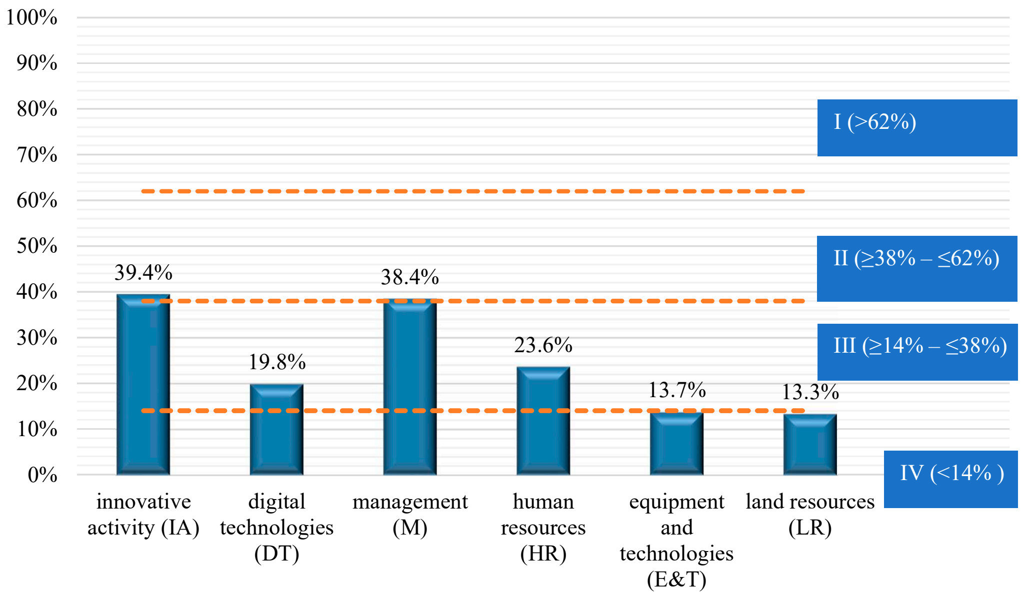

Fig. 2. Block parameters in the analyzed organizations of the Akmola region

Table 5

Screening assessment of ADA analysis with establishment of the digitalization level

Block	max, point	Threshold values				Result points	Level
		I	II	III	IV		
IA	207	> 128.4	128.4–78.7	78.6–29.0	< 29.0	81.5	II
DT	207	> 128.4	128.4–78.7	78.6–29.0	< 29.0	39.0	III
M	138	> 85.6	85.6–52.4	52.3–19.3	< 19.3	53.0	II
HR	161	> 99.8	99.8–61.2	61.1–22.5	< 22.5	37.0	III
E&T	161	> 99.8	99.8–61.2	61.1–22.5	< 22.5	28.0	IV
LR	207	> 128.4	128.4–78.7	78.6–29.0	< 29.0	32.0	IV

The amount of revenue growth during the implementation of the digital platform was calculated in accordance with three groups of effects: increased productivity, quality, and speed of new product launch (Table 6).

Table 6

Revenue growth with the introduction of a digital platform

No.	Types of effect	Change, %	Base, USD	Effect, USD
1	Increased productivity			34,137.35
1.1	Reduction of direct costs	2.0	873,417.72	17,468.35
1.2	Reduction of working hours	2.0	826,473.11	16,529.47
1.3	Reduction of the tax base due to depreciation	0.5	27,906.33	139.53
2	Improving the speed and quality of product output			6,209.62
2.1	Price increase	3.0	22,177.22	665.32
2.2	Increase in sales volume	3.0	166,329.11	4,989.87
2.3	Reducing the cost of warranty obligations	5.0	11,088.61	554.43
3	Process optimization			1,386.08
3.1	Acceleration of technological processes	1.0	16,632.91	166.33
3.2	The abolition of inefficient technologies	2.0	27,721.52	554.43
3.3	Reduction of stocks and warehouses	2.0	33,265.82	665.32
Total				41,733.05

The overall cost structure is balanced and reflects an integrated approach to the introduction of digital technologies in agriculture. At the same time, the allocated funds make it possible to create a modern, scalable and secure digital infrastructure capable of ensuring the effective functioning of all components of the agro-industrial complex in the region.

5. 2. Evaluating the effectiveness of a digital platform

The calculation of the final indicators characterizing the effectiveness of the use of the digital platform by crop production in the Akmola region: investment profitability, PI index, return on investment (Table 7).

Table 7

Final performance in the implementation of the digital platform

Indicator	Unit of measurement	Result
Revenue growth	USD	42,567.70
Expenses	USD	34,005.65
Return period	years	0.8
Yield index (PI)	Coefficient	1.3
Investment profitability for the first year	%	25.2

The obtained indicators are within the optimal values for investment projects in the agricultural sector and indicate the correctness of the selected technical and software solutions, as well as the effectiveness of the proposed model for the introduction of digital technologies.

5. 3. Econometric analysis of the dependence of economic potential on the level of digitalization

A regression analysis was conducted to statistically test the hypothesis of the relationship between the level of digital development of an enterprise and its ability to benefit from an industry platform. The dependent variable (Y) was the estimated revenue growth potential of the i-th enterprise from using the platform, expressed as a percentage of annual turnover (based on data for a realistic scenario). The key independent variable ($X1$) was the integral score of the enterprise according to the ADA model. To control other factors, the following were included in the model: the size of the enterprise, measured as the logarithm of the acreage ($X2$), and the indicator of its current operating profitability ($X3$). The following multiple linear regression model was evaluated (1)

$$Y = \beta\_0 + \beta\_1X1 + \beta\_2X2 + \beta\_3X3 + \varepsilon, \qquad (1)$$

where Y – the revenue growth potential of the i-th enterprise from using the platform (% of turnover); $X1$ – the integral score of the enterprise according to the ADA model; $X2$ – logarithm of the enterprise area; $X3$ – the level of the company's operating profitability (%); β_0, β_1, β_2, β_3 – estimated coefficients of the model; ε – random error term for the i-th enterprise.

Table 8 shows the results of the regression analysis.

Thus, enterprises with higher initial digital development have significantly greater potential to benefit economically from participating in an industry-specific digital platform. The control variables showed the expected positive impact of the size of the enterprise, while the current profitability did not have a statistically significant effect, which indirectly indicates that the potential of digitalization is equally accessible to both high- and low-profit farms.

Table 8

The results of the regression analysis of the impact of the level of digitalization on the potential of economic effect

Variable	Coefficient (β)	The standard error	t- statistics	p-value
Constant (β_0)	–1.92	0.91	–2.11	0.049*
Integral score ADA ($X1$)	0.327	0.088	3.72	0.002**
Area logarithm ($X2$)	0.41	0.17	2.41	0.027*
Profitability level ($X3$)	0.065	0.047	1.38	0.184
Calculation result:				
R^2	0.703			
Adjusted R^2	0.648			
F-statistic	12.64 (p = 0.0001)			

Note: * – $p < 0.05$; ** – $p < 0.01$.

5. 4. Scenario analysis of the economic efficiency of the implementation of the platform

To account for market uncertainty and the variability of the implementation process, a scenario assessment of the economic results of the project was carried out based on the methodology described. Three scenarios were considered: pessimistic, realistic (basic) and optimistic (Table 9).

These results emphasize that the final economic efficiency directly depends on the degree of involvement of enterprises, which correlates with their initial level of digital development.

Table 9

Comparative results of the implementation of the digital platform by scenarios

Indicator	Unit of measurement	The pessimistic scenario	Realistic scenario	An optimistic scenario
The coefficient of realization	–	0.6	1.0	1.4
Target enterprise coverage	%	~40	~70	~90
Revenue growth	thousand USD	25.5	42.6	59.6
Total costs	thousand USD	34.0	34.0	36.0
Payback period (PP)	years	1.33	0.80	0.60
Yield index (PI)	Coefficient	1.07	1.25	1.66
Return on investment (ROI), year 1	%	14.8	25.2	36.7

5. 5. Assessment of the cost structure and integrated effectiveness of the implementation of the platform

A detailed analysis of the cost structure for the implementation of the digital platform, presented in Table 10, demonstrates a balanced distribution of investments between key components. The main share of the financing – 43.2% (USD 14,695) – is aimed at the formation of a centralized technical infrastructure, including server equipment and data storage systems with redundancy, which ensures the reliability and scalability of the platform. Another 22.1% (USD 7,515) was invested in user jobs (computers and office equipment), creating the necessary tools for staff.

Table 10

The cost structure for the implementation of the digital platform

Cost component	Amount, USD	Fraction, %	Rationale and key elements
Technical infrastructure	14,695	43.2	Server equipment, data storage and backup systems, network equipment, uninterruptible power supply
Computers and office equipment	7,515	22.1	Equipping workplaces for key users in enterprises and in the coordination center
Software and security	8,165	24.0	Licenses for basic and specialized software (ERP modules, GIS, analytics), interface development, cybersecurity and data protection system
HR support (training and support)	3,630	10.7	Development of training programs, conducting trainings for the personnel of enterprises, the salary of technical support specialists for the first year
Total	34,005	100.0	The cost of implementing a digital platform

A significant share of the costs (24.0%, or USD 8,165) is directed to software, including not only basic licenses, but also specialized modules for geographic information analysis (GIS) and forecasting, as well as the implementation of comprehensive information security measures. It is critically important to allocate 10.7% of the budget (USD 3,630) to the HR component – staff training and technical support. This investment in human capital is directly aimed at overcoming the limitation identified in section 5.1 – the low median level of development of the "Human resources" block among the analyzed enterprises. Increasing the digital competencies of employees is a prerequisite for accelerating adaptation and achieving the depth of use of the platform's functionality, which ultimately determines the realization of its economic potential.

6. Discussion of the results of platform implementation and digital development assessment

As follows from Table 3, the sample covers enterprises with a wide range of scales of activity – from relatively small to the largest in the region, which provides a variety of data for analysis. The high share of crop production in turnover (on average 94%) confirms the correctness of the study focus on this particular activity, even within the framework of integrated holdings.

Based on the analysis of the Table 4, the following conclusions can be drawn about the distribution of companies by levels of digitalization: 29% of companies demonstrate a stagnant level, 52% of the subjects studied have a starting level, and 19% of organizations have a developing level. Thus, most of the subjects studied are at the initial level of digitalization of activities. At the same time, a significant proportion of companies with a stagnant level is noticeable, which indicates the need to strengthen measures for digital transformation in the agricultural sector.

The most developed blocks are innovative activity (IA) and management (M), from which it is possible to conclude that there are fewer factors that negatively affect production modernization and the development of organizational management methods (Table 5). The human resources (HR) and digital technologies (DT) blocks are at the median level, while equipment and technologies (E&T) and Land resources (LR) are at a low level (Fig. 2).

The analysis of the costs of implementing a digital platform demonstrates the optimal allocation of resources between key infrastructure components (Table 6). Technical means form the basis of the platform and ensure its reliable operation, while their cost is justified by the functionality and performance of the equipment. Computers and office equipment form the necessary working tools for staff, providing a modern level of workplace equipment. The software includes a complete set of necessary components for the functioning of the system, including information security measures. Special attention is paid to the HR component, which emphasizes the importance of the human factor in the process of digitalization.

The calculations performed demonstrate the high economic efficiency of implementing a digital platform in the agro-industrial complex of the region (Table 7). IRR = 1.3 and PP = 0.8 years indicate a rapid return on investment and a promising project. An increase in revenue of 42,567.70 USD at a cost of 34,005.65 USD ensures an investment return of 25.2% in the first year of operation, which confirms the feasibility of the project.

The results presented in Table 8 confirm the presence of a statistically significant positive relationship between the level of digital development of an enterprise ($X1$) and its potential for revenue growth from using an industry platform (Y). The coefficient for the variable "ADA Integral Score" ($\beta_1 = 0.327$) is statistically significant ($p = 0.002$). This indicates that an increase in the overall level of enterprise digitalization by 1 point on the ADA scale is associated with an average increase in potential revenue growth from the platform by 0.327% of the company's turnover.

Scenario analysis demonstrates the sustainability and investment attractiveness of the project. Even in a pessimistic scenario characterized by low adaptation and the realization of only 60% of the potential, the project remains profitable (PI > 1) and pays off in 1.33 years, providing an ROI of 14.8%. A realistic scenario confirms high efficiency with a fast PP and a PI above 25%. The optimistic scenario, assuming high participant engagement and the emergence of network synergetic effects, shows maximum returns: PP is reduced to 0.6 years, and the return on investment exceeds 36% (Table 9).

The calculation of the integral budget efficiency ratio (CBR) for a realistic scenario for the first year gives a value of 1.25 (42.568 USD / 34.005 USD), which indicates that each dollar invested generates 1.25 USD of income. In terms of components, investments in analytical software and staff training demonstrate the highest returns, where the indirect effect of optimizing solutions and reducing errors is many times higher than the direct costs (Table 10).

The study showed that the indicators of the engineering/technology blocks and land resources have the lowest level of use of digital technologies in the studied enterprises. At the same time, they are one of the most important areas of digital change in crop production, and their development requires large financial investments [24]. With the intensification of the use of digital tools in this block, it becomes possible to achieve an economic effect in the short term.

Full digitization of land resources is a prerequisite for the integration of crop production enterprises into the digital platform. The capabilities of the geoinformation system and remote sensing of the earth will allow for complex land use analysis and operational monitoring. The study [25] obtained a similar result that the human resource (HR) of agricultural enterprises in a developing country is insufficiently involved in the processes of digitalization, which hinders the innovative development of agriculture. However, a comparison has been made with other types of enterprise resources, which is presented in this study.

The platform automatically logs and saves every transaction performed. Due to this, the economic processes carried out through the platform become open and accessible for analysis. If all enterprises switch to work through such platforms, then the industry as a whole is gradually switching to digital format, becoming completely open and understandable. A multi-stage digital structure is being formed, covering the entire field of crop production.

Unlike many studies [26–28], where the assessment of the level of digital development of agricultural enterprises ends with a statement of the assessment results, our study suggests the introduction of a digital platform. The latter requires a high level of digitalization in enterprises.

The present study demonstrates the significant advantages of the proposed approach to digitalization of crop production in comparison with existing solutions. Unlike the platform proposed by [29], which focuses primarily on field and yield analytics, our development provides comprehensive integration of all production processes.

Compared to the solution [30] focused on local agri-food markets, the digital platform developed in this study offers deeper integration with production processes and expanded functionality for resource management.

The study [20] mainly considers information processing on smart farms, whereas our model covers the entire range of activities of crop production enterprises, including land resources and innovation activity.

In the study [31], based on the method of statistical analysis, as well as SWOT and PEST analysis, an assessment of the use of digitalization in the activities of agricultural enterprises in Ukraine and other European countries was carried out. This should be recognized as a broader study that provides universal results. However, the assessment of digitalization was carried out only in relation to control and accounting processes at enterprises. The ADA analysis methodology proposed in this study covers a differentiated range of indicators for assessing digitalization, including not only technological, but also managerial, personnel, and innovative aspects.

Thus, the proposed study makes it possible to fill a gap in science in assessing the digital development of enterprises in the field of crop production, which provides a more differentiated approach. The evaluation-based platformization solutions for crop production allow to take advantage of segmentation and the market.

The results of the scenario analysis deepen the interpretation of the main conclusions, moving from assessing the current state to predicting development trajectories. The analysis confirms the key thesis of the study hypothesis: the economic effect of implementing a specialized digital platform directly depends on the initial level of digital development of enterprises, estimated using an integrated model. At the same time, scenario modeling reveals the non–linearity of this dependence and specifies vulnerable points: the low level of digitalization in key production blocks – "Equipment and Technologies" (E&T) and "Land Resources" (LR) – acts as a critical "digital barrier". It is this barrier that in a pessimistic scenario leads to delayed payback and low engagement, reducing the potential effect even with the presence of the platform itself.

Thus, the scenario approach makes it possible to transform the hypothesis into a management strategy. Shifting the result from pessimistic to realistic and optimistic scenarios requires not parallel, but sequentially synchronized action: the implementation of an integrating platform should be accompanied by targeted measures to develop precisely those components of digital development (E&T and LR) that, as the ADA analysis has shown, are lagging behind the most and at the same time are critical for extracting platform benefits. benefits. Without such synchronization, ensuring the readiness of the "digital soil", investments in platform solutions may not reach the threshold of economic efficiency predicted in the baseline scenario.

The analysis also shows that the economic effect has a pronounced network character. Increasing the number of connected and active enterprises non-linearly enhances the usefulness of the platform for each participant (synergy effect) and reduces the unit cost of its maintenance. This forms an economic justification for stimulating broad participation and building coalitions of stakeholders (the government, large agricultural holdings, technology suppliers), which is a key condition for the implementation of an optimistic scenario.

This study has the following limitations:

– the geographical limitation of the sample of enterprises within the region of one country, which may affect the generalization of the results;

– the time factor of the study does not allow tracking the long-term dynamics of changes in the process of digitalization;

– methodological limitations are related to the fact that ADA analysis focuses primarily on quantitative indicators.

The limits of applicability of the obtained results. The structure of the agricultural sector, the level of equipment and access to digital technologies in other regions of Kazakhstan (especially in the southern and western regions with different specialization and scale of farms) may differ significantly. Therefore, direct generalizations of the conclusions at the national level are incorrect.

Disadvantages of the study:

– the economic calculations of the platform's effects and scenarios for its implementation are based on modeling, which is a standard approach at the conceptual design stage, but does not reflect the actual implementation;

– the paper focuses on the main aspects of the platform solution, but individual technical and integration risks, as well as possible interactions with existing local systems, should be considered in more detail at the next stages of the project.

Prospects for further study include:

– expanding the geography of the study to obtain more representative data on the level of digitalization of crop production;

– long-term monitoring of the implementation of the digital platform to assess its impact on productivity and efficiency;

– in-depth analysis of individual blocks of the ADA model to identify specific digitalization problems in each area;

– investigation of the impact of the platform solution on the competitiveness of crop production enterprises in the long term;

– adaptation of the ADA analysis model to the specifics of other agricultural segments, taking into account their characteristics and the level of digitalization development.

7. Conclusions

1. Based on the ADA-analysis methodology, the study assessed the readiness of enterprises for digital transformation, the level of digitalization of 21 large crop production enterprises in the region, and calculated the economic effects of the introduction of a digital platform. An analysis of 21 enterprises showed the absence of companies with an active level of digitalization, while 29% have a stagnant level, 52% are start-up and 19% are developing, with the blocks "Innovative activity" (81.5 points, level II) and "Management" (53.0 points, level II) as the most developed, and "Equipment and technologies" (28.0 points, level IV) and "Land resources" (32.0 points, level IV) like laggards.

2. The implementation of the digital platform ensures revenue growth of USD 42,567.70 at an expense of USD 34,005.65, a payback period of 0.8 years, a profitability index of 1.3 PI and a return on investment of 25.2%. This will lead to an improvement in the quality of production processes, improved control over land resources and accelerated implementation of innovative technologies.

3. Regression analysis confirmed a statistically significant positive dependence of the revenue growth potential on the ADA integral score ($\beta_1 = 0.327$, $p = 0.002$) with $R^2 = 0.703$ and F-statistics of 12.64 ($p = 0.0001$). This means that the revenue of enterprises will grow in parallel with the increase in the level of their digital development.

4. Scenario analysis showed the payback of the project in 1.33 years in a pessimistic scenario (PI = 1.07, revenue growth of 25.5 thousand USD), 0.80 years in a realistic one (PI = 1.25, growth of 42.6 thousand USD) and 0.60 years in an optimistic one (PI = 1.66, growth of 59.6 thousand USD). The implementation of this strategy, based on scenario forecasting data, will minimize investment risks, accelerate the transition to realistic and optimistic development scenarios, and ensure the long-term sustainability of the digital transformation of crop production in the region.

5. The cost structure for the implementation of the platform is USD 34,005, where 43.2% (USD 14,695) is allocated to technical infrastructure, 24.0% (USD 8,165) to software and security, and the integral budget efficiency coefficient CBR is 1.25 in a realistic scenario. The implementation of the proposed recommendations will lead to an improvement in the quality of production processes, improved control over land resources, and accelerated implementation of innovative technologies.

Conflicts of interest

The authors declare that they have no conflict of interest in relation to this study, whether financial, personal, authorship or otherwise, that could affect the study and its results presented in this paper.

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The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

In this paper, the authors used Claude 3.5 Sonnet and Gemini 2.5 Pro for grammatical, linguistic, and stylistic correction. The authors manually checked and edited the material and confirm that the AI tools were only auxiliary and were not used for generating and formulating the hypothesis, methodology, analyses of the results, or drawing conclusions.

Authors' contributions

Botagoz Duissenbayeva: Conceptualization, Methodology; **Raushan Gabdualiyeva:** Supervision, Writing – review & editing; **Gulnar Kunurkulzhayeva:** Supervision, Project administration, **Zhaxat Kenzhin:** Validation, Writing – original draft; **Aisulu Parmanasova:** Investigation, Visualization; **Yerlan Onlassynov:** Resources, Data curation, Formal analysis; **Shynar Nurgaliyeva:** Methodology, Validation; **Almagul Ibrasheva:** Visualization, Writing – original draft; **Gaukhar Kairliyeva:** Project administration, Data curation; **Wasiu Abiodun Sanyaolu:** Resources, Writing – original draft.

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