Review and prospects of information technologies management in agriculture

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ABSTRACT

The paper presents research and review articles published between 2014 and 2023 on the use of cloud technologies and blockchain for smart agriculture development in Russia, China and the Republic of Belarus. The main directions of modern agriculture digitalization have been listed. The comparison of technical progress of agriculture in Russia and neighboring European countries (Poland and Latvia) has been carried out. The survey results show that in Russia advanced developments consider soil-climatic and agro-technological peculiarities of the territory, cloud technology providers and own data processing centers are being developed. Some practical systems are not unified, computing resources are geographically distributed, and less than 8–10 % of farms in Russia use digital platforms. Promising research directions of modern technologies and their application in agriculture have been described. The article studies information technologies used in intelligent agriculture based on cloud computing and blockchain. Intelligent agriculture is characterized by large amounts of data. Data transmission and analysis in such information system are based on cloud technologies. Agro-production processes are linked to other parts of the value chain in complex, highly automated production, and logistics chains involving wholesalers, retailers, logistics, agricultural producers, and their suppliers. Such chains can reduce food costs and retail prices, as well as the need for production and distribution capacity. Supply and value chains digitalization and digital platforms development that connect participants in the agroecosystem are driving the use of blockchain.

KEYWORDS

Modern agriculture, smart farming, information technology, cloud computing, blockchain, artificial intelligence, fuzzy logic, digitalization

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АННОТАЦИЯ

Представлены исследования и обзорные статьи, опубликованные в период с 2014 г. по 2023 г., посвященные использованию облачных технологий и блокчейна для развития интеллектуального сельского хозяйства в Российской Федерации (далее – РФ, Россия), Китае и Белоруссии. Перечислены основные направления цифровизации современного сельского хозяйства. Проведено сравнение технического прогресса сельского хозяйства в РФ и соседних европейских странах (Польше и Латвии). Результаты опроса показывают, что в РФ передовые разработки учитывают почвенно-климатические и агротехнологические особенности территории, развиты поставщики облачных технологий и собственные центры обработки данных. Отмечено, что некоторые практические системы не унифицированы, вычислительные ресурсы географически распределены, а цифровыми платформами в РФ пользуются менее 8–10 % фермерских хозяйств. Описаны перспективные направления исследований современных технологий и их применения в сельском хозяйстве. Настоящее исследование посвящено информационным технологиям, применяемым в интеллектуальном сельском хозяйстве на основе облачных вычислений и блокчейна. Для интеллектуального сельского хозяйства характерны большие объемы данных. Передача и анализ данных в такой информационной системе основаны на облачных технологиях. Процессы агропроизводственного цикла связаны с другими звеньями цепочки создания стоимости в сложных высокоавтоматизированных производственных и логистических цепочках, охватывающих оптовые и розничные торговые компании, логистику, сельскохозяйственных производителей и их поставщиков. Такие цепочки могут снизить себестоимость и розничные цены на продукты питания, а также потребность в производственных и сбытовых мощностях. Цифровизация цепочек поставок и создания стоимости, развитие цифровых платформ, объединяющих участников агроэкосистемы, приводят к использованию блокчейна.

КЛЮЧЕВЫЕ СЛОВА

Современное сельское хозяйство, интеллектуальное земледелие, информационные технологии, облачные вычисления, блокчейн, искусственный интеллект, нечеткая логика, цифровизация

ДЛЯ ЦИТИРОВАНИЯ

Матвейчук Н.М., Сотсков Ю.Н., Михайлов А.Ю. Обзор и перспективы развития управления информационными технологиями в сельском хозяйстве Российской Федерации, Китая и Белоруссии//E-Management. 2024. Т. 7, № 3. С. 4–19.

БЛАГОДАРНОСТИ

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INTRODUCTION

Agriculture 1.0, or traditional agriculture, is based on the use of conventional labor with low productivity (this stage includes the early 20th century). Agriculture 2.0 is characterized by extensive use of mechanization, fertilizers, and crop protection products with dramatic increases in yield potential (Agriculture 2.0 was initiated in the 1950s). Agriculture 3.0 is based on precision farming technologies such as pointing technology, variable rate application technologies, telematics, data management with a higher degree of precision operations, and the use of IN to generate data through sensors and GPS (Agriculture 3.0 was launched in the early 1990s).

Agriculture 4.0 and Agriculture 5.0 are referred to as digital, or smart, agriculture. Different approaches to define the concept of Agriculture 4.0 are analyzed [Bouri et al., 2021; Bouri et al., 2021]. The smart agriculture term is used in the agricultural sector aimed at optimizing farmers' activities to increase production efficiency and intellectualizing the farming system. The implementation of smart systems (smart farm, smart field, smart garden, smart greenhouse, and smart agricultural enterprise) is possible through the use of modern digital information technology.

The present study focuses on information technologies applied in smart agriculture based on cloud computing and blockchain. Intelligent agriculture is characterized by a large amount of data. Data transmission and analysis in an such information system are carried out on the basis of cloud technologies. Agro-industrial production cycle processes are linked to other links in the value chain in complex, highly automated production and logistics chains involving wholesalers, retailers, logistics, agricultural producers, and their suppliers. Such networks can reduce food costs and retail prices, as well as the need for pro operations and distribution capabilities. The digitalization of supply and value chains and the development of digital platforms that connect participants in the agroecosystem are leading to the use of blockchain.

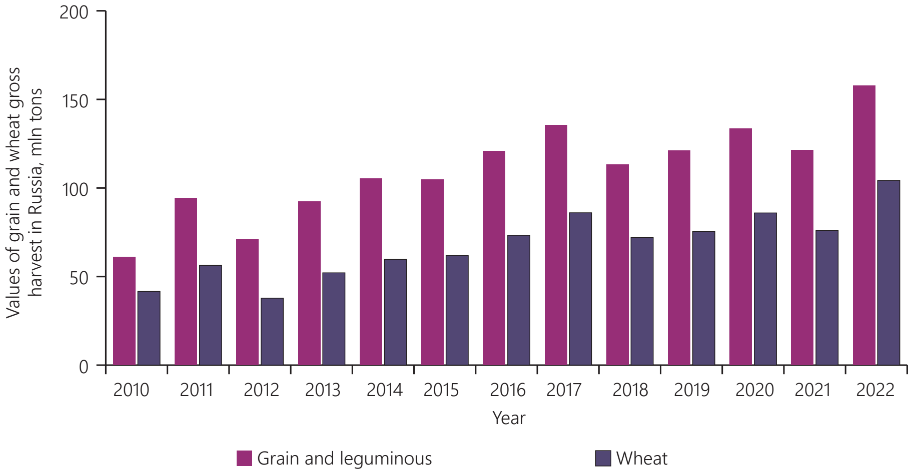
AGRICULTURAL DEVELOPMENT

Since there are many surveys on modern information technologies and their implementation, it is necessary to explain why this survey can be useful. The main purpose of this survey is to summarize the current status of smart agricultural technologies in the literature published in Russian.

The reason for the interest in such publications is based on the rapid growth of agriculture and food production in the Russian Federation (hereinafter referred to as Russia). While in the period from 2012 to 2016, agricultural exports amounted to about USD 20 billion per year. In the period from 2012 to 2016, agricultural exports amounted to about USD 30 billion per year; in 2020 it increased to USD 30 billion. In 2021, it was equal to USD 37.1 billion. In 2022, it was USD 41.6 billion, and USD 41.6 billion in 2022. In the export structure, almost one third is grain, 20 % is oil and fat products, and 18 % is fish and seafood.

Russia's agro-industrial complex is currently actively developing. Agricultural production is showing significant growth. The country has been the world leader in wheat exports since 2016, despite the fact that in the 1990s it was the largest importer in the world. Since 2021, Russia has been the world's top grain exporter, with 5 % of the global market and 20 % of the global wheat market. Export volumes of grain and wheat products are shown in Fig. 1 and in the Table.

The Digital Economy of the Russian Federation National Program was approved in 2017, and the Digital Economy National Project has been in effect since 2019. It envisages the transformation of priority sectors of the economy and social sphere, including agriculture, through the introduction of digital technologies and platform solutions. It includes such federal projects as Digital Technologies and Artificial Intelligence. The main goal of the digitalization of agriculture is to ensure stable productivity growth while reducing costs and energy consumption, increase the efficiency of land use, reduce production costs and increase added value, improve the quality and efficiency of management decision-making, as well as improve working conditions and increase the prestige of agricultural professions. Active implementation of digital technologies is one of the key factors in improving the competitiveness of the agro-industrial complex, which allows to ensure high rates of production development, increase employment, and motivate personnel to work in agriculture [Candila et al., 2021; Saqib et al., 2021; Yumashev, Mikhailov, 2020].



Source[1]

Fig. 1. Gross collection in Russia from 2010 to 2022

Table. Export of crop production

Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Grain exports, in million tones	14.0	18.8	23.2	19.6	30.7	31.6	44.5	56.2	56.2	40.5	57.5	43.1	60.8
Wheat exports, in million tones	11.9	15.2	16.1	13.8	22.2	21.2	25.3	32.8	43.9	31.8	38.3	32.9	46.7

Source[2]

The increased attention of the Government of the Russian Federation to the digital technologies' development is based not only on the desire to improve the efficiency of agricultural production but also on the need to reduce the technological gap between Russia and Western countries, ensuring the formation of digital agriculture. After the adoption of the National Program in 2017, the number of publications devoted to the problems and achievements in the field of digitalization of agriculture has increased significantly. Due to the absence of any survey with publications in Russian in the field of modern agriculture, the present study can be seen as an attempt to bridge this gap [Náñez Alonso et al., 2021; Fadeyi et al., 2019; Guidi et al., 2020].

[1] Federal State Statistics Service. Bulletins on the agriculture state. Access mode: https://rosstat.gov.ru/compendium/document/13277 (accessed 31.07.2024).

[2] Ibid.

Russia is becoming a major exporter of grain in contrast to Europe, which is an importer. Russia and other countries of the former Soviet Union outside the European Union (hereinafter referred to as EU) are characterized by large corporate farms, high farm productivity, and a low yield gap, approaching the New World and Europe in this respect. In contrast, Europe is characterized by small and medium-sized farms, modern agriculture, and thus high farm productivity with a small yield gap, but with subsidized agriculture and increasing regulation of agriculture for environmental reasons. EU countries have common agricultural policies and projects. In particular, the EU has a program of Common Agricultural Policy (hereinafter referred to as CAP), which develops organic farming with the aim of preserving the environment (the latter is implemented, for example, in Poland within the framework of the Program). There are reviews of common agricultural development projects implemented in the EU [Siddique et al., 2023; Jia, Li, 2023; Benhamed et al., 2023].

Next, we take a closer look at technical progress in Poland and Latvia. These countries are chosen as suitable examples because they are neighbors of Russia and Belarus in the European Union, while one was part of the Soviet Union and the other was not. In recent years, the number of farms has declined dramatically in all EU countries, especially Poland. Farms are getting bigger, which often leads to higher productivity. This trend is expected to continue. It was also noted that individual and small-scale farming was traditionally the norm in Poland until 1989, while in the other Baltic countries, including parts of Russia and Latvia, many small farms have been merged into large collective farms. Although agriculture on the Baltic coasts today operates under relatively similar market conditions, the legacy of different historical paths can still be seen in the stark differences in the distribution of farm sizes across the EU.

A systematic review of the use of farming patterns to assess the impact of policies on agriculture in the European Union is conducted. Farm models are identified, and it is shown that EU countries closest to Russia, such as Latvia and Poland, use far fewer different farm models (apart from four common models, only one was identified in Latvia and four in Poland) compared to several dozen in Western European countries. The number of publications devoted to agricultural research in these countries was small.

Technical progress in Polish agriculture in the context of the implementation of the sustainable development concept is analyzed. Many farms are modernized through investments such as the implementation of energy-saving production technologies or the use of renewable energy sources, in particular biogas plants. The use of CAP in Poland is reviewed, considering bioeconomy implementation, which provides resource-efficient and sustainable biomass production models.

A review of sustainable small farming strategies implemented in five regions in Poland and Latvia shows that the average size of small farms in these regions was similar, except for one region in Latvia where it was significantly higher.

The challenges faced by farmers and their sustainability strategies fall into the following categories:

1) economic shocks – price volatility, distorted terms of trade (including the Russian trade embargo), lack of financial resources (in Poland, extreme fragmentation of farmland results in small farms being prevented from receiving direct payments because plots are too small to receive government support), restrictive government regulations;

2) social shocks – aging and deteriorating health (although Poland ranks best in the EU in terms of the age structure of farm managers), limited prospects for succession, depopulation, changing consumer habits;

3) environmental disturbances – unfavorable weather conditions, threats to animal health, unsustainable farming practices.

All the aforementioned major disruptions are common to both countries, indicating that smallholder farmers face common challenges irrespective of the size of the state, albeit with common political, economic, geographical, and climatic factors in both economies.

The following sustainability strategies are identified:

– dependence on state support (the majority of farms surveyed in Poland and Latvia indicated that they receive EU support);

– going underground, diversification (in Polish small farms less than one fifth receive income from agriculture alone);

– repurposing and improving technologies (these are not necessarily advanced and high-tech solutions as many small farms cannot afford large investments and use the opportunities provided by attracted project financing to purchase necessary machinery and agricultural equipment);

– prioritization;

– outsourcing;

– individualized training (e.g., learning to use computers and more advanced software);

– informal cooperation and seeking advice.

In Latvia, they mainly relied on informal advice from colleagues and online resources, seeking personal advice from professionals on specific issues; in Poland, they use public extension services.

Latvian farmers use different areas of “precision” farming: “precision” crop production, “precision” animal husbandry, “precision” horticulture, “precision” beekeeping, “precision” greenhouse farming, and “precision” berry (cranberry) growing. The technology of such farming in independent Latvia appeared in the 2000s, mainly in large farms of more than 1 thousand hectares. Farmers focused on soil analysis and yield mapping. In the following years, fertilizer maps and different application technologies started to be used.

Nationally, small farms of 10–19.9 hectares account for the largest share of the farmland structure by farm size. In 2015, small farms with one to five cows accounted for 77 % of all farms. Mostly imported sensors and software (from Germany and Norway), field robots and drones (developed by Sweden, the Netherlands, and Germany) are used, although Latvia conducts its own research in the field of “precision” farming, including monitoring of yields and weeds, environmentally friendly grain drying, the influence of plow parameters on plowing efficiency, and the influence of soil moisture on energy consumption during plowing. In the near future, it is planned to develop these technologies on small and medium-sized farms.

The introduction of digital agriculture in Russia faces the following difficulties:

– shortage of agricultural machinery due to poor development of mechanized technologies;

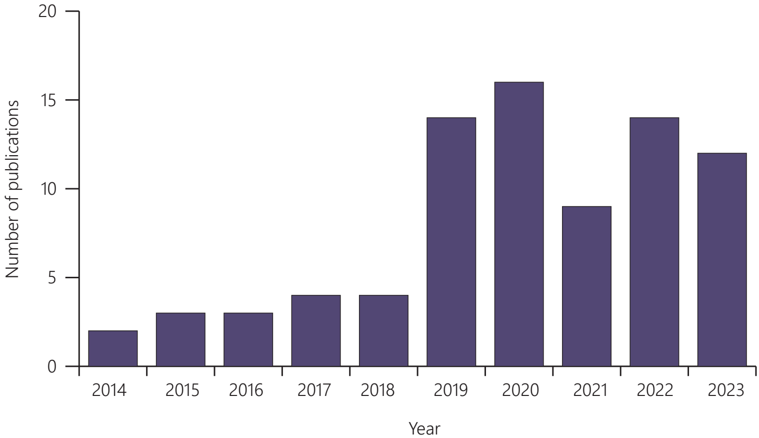
– low level of implementation of precision farming due to lack of experience with these technologies in most agricultural enterprises;

– insufficient number of leading Russian information technology (hereinafter referred to as IT) companies like Amazon, Apple, Google, IBM, Intel, Microsoft, etc., weakens the potential for breakthroughs in the creation and development of such revolutionary technologies as cloud platforms, blockchain, artificial intelligence, and robots.

The peculiarities of domestic agricultural enterprises that complicate the process of their digitalization are that computing and information resources are geographically distributed while highly localized and variable. The prevalence of the Internet and other means of communication in rural areas remains relatively low, which is insufficient for the development of IT infrastructure for distributed agricultural production management systems. Some publications point out the lack of specialists providing databases of such systems and effective algorithms for control scenarios (devices, installations, and processes). All these features lead to the fact that less than 8–10 % of farms in Russia currently use digital platforms. In addition to the geographical remoteness of agricultural enterprises, the specifics of the country are determined by the presence of numerous small farms and peasant yards along with large agricultural holdings. The latter have great opportunities for digitalization and automation of agricultural production.

IMPORTANCE OF E-MANAGEMENT

The present study was conducted by reviewing existing research articles. Most of the studies in the scientific electronic library SCOPUS were included in the review. We used the “cloud technology” keyword in the Agriculture and Forestry section of the eLibrary. In total, the initial search identified 431 publications of potential interest, and their titles were selected based on the context of the study [Podhorsky, 2023; Jabłczyńska et al., 2023; Nerem, Gaur, 2023; Sarkodie et al., 2023]. In particular, publications on farmers' education were excluded. Of the 431 publications, 87 remained, of which were reviewed with abstracts and texts. After that, another 6 articles that were not related to research in Russia, China, or the Republic of Belarus were removed. The number of reviewed papers in Russian for the year is presented in Fig. 2. Of the selected articles, only three were published in English, while the rest were published in Russian.



Source[3]

Fig. 2. Distribution of peer-reviewed papers by year for the period of 2014–2023

Despite the fact that in terms of the level of agricultural production in Russia, 17.8 % of agricultural producers used cloud services, 11.6 % used the Internet of Things (hereinafter referred to as IoT), and 2.2 % used artificial intelligence technologies, about 5 % of agricultural producers use the latest robotization tools, just over 40 % of agricultural organizations work with electronic document management systems, and no more than 7 % use training programs [Wang et al., 2021; Han et al., 2019; Thuy and Khai, 2020; Li et al., 2019].

In 2021, 10.5 % of households in Russia used some form of digital technology (including 10.4 % of organizations involved in growing annual crops and 9.3 % of organizations involved in animal husbandry), while in the Republic of Belarus, 10 % of arable land is cultivated using digital technologies. The main cross-cutting digital technologies used in agriculture include cloud technologies and geographic information systems, technologies for collecting, processing, and analyzing big data.

Adoption and utilization of digital technologies in the agricultural sector is a costly and time-consuming process. The costs required to scale up and use such technologies in agriculture, forestry, hunting, fishing, and fish farming include the following parts: information security; purchase of digital equipment, as well as modernization and maintenance; purchase of software, its adaptation and modification; training of employees in the use of digital technologies and payment for telecommunication services; purchase of computers, office equipment, and means of communication; payment for access to the Internet.

The basis for the use of modern information technology is cloud and fog computing technologies. The markets of cloud computing in Russia and abroad are considered, and the leaders of the cloud services market are listed. In 2013, there was a sharp decline in the software market, while the volume of transactions

[3] Scopus. Access mode: https://scopus.com (accessed 31.07.2024).

in the cloud computing market continues to increase, which indicates that customers are becoming more interested in moving their data to cloud storage and using software from the cloud under the SaaS model.

The types and models of cloud services present in the domestic market and the main trends and prospects of the Russian cloud computing market are analyzed. The frequently used model of access to cloud technologies is the SaaS model, while the greatest growth is demonstrated by digital platforms in the agro-industrial complex, realized on the PaaS technologies.

A number of provisions and recommendations on the digitalization of agriculture derived from the studied experience of EU countries are formulated. The use of digital technologies by farmers and small producers requires special attention, as they are the most vulnerable link in the digital transformation of agricultural business. It is necessary to reduce the digital divide between large and medium-sized producers and to increase the training of farmers in best practices of digitalization using online resources and platforms.

It should be noted that in previous years, articles were devoted to the analysis and implementation of Western technologies and global experience; it was also suggested to adapt and implement Western cloud platforms and information systems in domestic agricultural enterprises. In the last two years, the focus has been on accelerating the development of Russia using cloud technologies and creating cloud data centers in the country to ensure food security and increase the competitiveness of domestic agricultural products [An et al., 2024; Mikhaylov et al., 2023; Moiseev et al., 2023].

The development and use of automated information systems for information support of decision-making at all stages of the production process are important components of the development of the agro-industrial complex. These systems represent a digital platform consisting of software and hardware, devices, and specialized professional information systems. The objectives of the digital platform are the collection of primary information from the environment, its unification, and further development of digital standards for information resources. The maximum efficiency of digitalization of production is achieved through the use of integrated technologies, methods of working with big data, and cloud services, as in this case information becomes available to enterprises of different sizes, not only to individual large companies. The authors of the references point to the need to unify the management of agricultural enterprises at the federal and transnational levels, and numerous attempts have been made to develop appropriate digital platforms. A reference model of agriculture was created, consisting of unified databases of primary and technological accounting information and standard websites of enterprises with cloud storage on the basis of powerful database management systems.

In order to develop a model for the formation of an optimal digital platform in the agro-industrial complex, a number of cloud-based digital sub-platforms common to most agricultural organizations (such as a service for collecting and storing operational primary accounting information in a unified database, maintenance of a unified database of technological accounting, and an application service representing the software implementation of functional control tasks with a unified description of algorithms) have been identified.

PROSPECTS OF E-MANAGEMENT

The Ministry of Agriculture of the Russian Federation has developed and is implementing the following information systems [Qin et al., 2020; Tang et al., 2019; Yang et al., 2020; Jung et al., 2019; Chicarino et al., 2020]:

– Federal State Information System of Accounting and Registration of Tractors, Self-Propelled Vehicles and Trailers;

– System of Monitoring and Forecasting of Food Security of Russia;

– Integrated information system for collecting and processing accounting and specialized reporting of agricultural producers, formation of consolidated reports, monitoring, accounting, control and analysis of subsidies to support the agro-industrial complex (Subsidies to Agriculture Automatic Identification System (hereinafter referred to as AIS);

– Unified Federal Information System on Agricultural Land;

– State Information System "Information and Analytical System of Operational Monitoring and Risk Assessment of Agricultural Production. State and Risks of Scientific and Technical Support of Agricultural Development";

– Federal State Information System for Traceability of Grain and Grain Products (FSIS Grain);

– Mercury Federal State Information System of Electronic Veterinary Certification.

The following projects have been developed and implemented as part of the state program for the development of agricultural business in China or the Republic of Belarus:

– National AIS for the formation, maintenance and use of a unified register of agricultural plant varieties allowed for use in the territories of the member states of the Eurasian Economic Commission;

– State Technomonitoring AIS for collection, accumulation and processing of information on state registration of tractors, trailers and self-propelled machines, and state technical inspection;

– monitoring of maintenance of milking parlors at dairy complexes AIS;

– database and information retrieval system of the Ministry of Agriculture of the Russian Federation;

– machine and tractor fleet;

– AITS State Information System of Identification, Registration, Traceability of Farm Animals, Identification and Traceability of Livestock Products.

In all cases in the development of AIS, cloud data centers can be used as a data warehouse for analysis and forecasting based on available information [Zhang, 2020; Mikhailov, 2022; An et al., 2020; Mikhailov, 2021].

The most promising is the use of a hybrid model of cloud storage and local database. Information is accumulated in farmer databases and then exported to special cloud storage where it is consolidated. Summary tables, answers to user queries, and diagrams obtained from the common database can be used to monitor the state of farms in the region and effectively manage their activities. Irkutsk State Agrarian University developed a similar project of data storage using cloud technologies for the management system in the Ministry of Agriculture of the Irkutsk Region – the Multifunctional Cloud Platform "Smart Farmer 4.0" developed for small businesses and farms. Applications "Agro-industrial cluster", "Optimization of land resources use in the region", "Ecological and mathematical modeling of food production", "Drought", "Natural elements", "Risk management of agricultural production plans", "Modeling of crop bioproductivity", and "Planning of agro-technological operations" have been created. It is proposed to use Mail.Ru, i.e., cloud solutions as a cloud storage platform for the project.

Water distribution management systems on inter-farm irrigation systems are considered. Processes of irrigation system design and operation are analyzed. There is a need to focus software on mobile devices, in the development of cloud services and methods of processing large amounts of data. Models, algorithms, and procedures for managing water distribution in inter-farm irrigation systems that ensure guaranteed equitable water distribution based on the principles of sustainability and uniformity of water supply, minimization of unproductive water consumption, and maintenance of objective statistics on a wide range of management quality indicators have been developed. The work focuses on the unification of irrigation systems through the development of a management decision support system (DSS). The advantage of using web-cloud technology, which provides the user with resources in online service mode and as a software platform for DSS, is established. Based on the analysis of leading companies' proposals in terms of cloud technology services, a DSS for water distribution based on Google services is developed [Goodell, Goutte, 2021; Grobys, Huynh, 2021; Hamill et al., 2021; Hasan et al., 2021].

A conceptual model of industrial Internet of Things is proposed, in which cloud computing is performed through distributed computing using blockchain technology. The application of this approach will further improve the efficiency of the enterprise by reducing the cost of using cloud services while improving the reliability of technological processes and information security.

A unified digital platform for agricultural production can be used in logistics as a digital tool for product tracking. A mathematical model of the digital logistics platform is proposed, which will provide real-time cargo tracking, reduce the labor intensity of the process, and increase trust between supply chain participants, which is important in the context of sanctions. The use of cloud platform technologies in this chain will provide an opportunity to move to direct sales when product delivery is managed through the automatic exchange of information between supply chain members via a cloud service while minimizing the use of warehouse and logistics infrastructure of wholesale intermediaries. The implementation of a digital logistics platform will allow for the most efficient implementation of smart contracts, artificial intelligence, and distributed ledger technologies in logistics.

Cloud accounting is virtually no different from desktop accounting. Economists note that the result of using cloud technology in accounting is a 50–70 % cost reduction due to the fact that now there is no need to purchase expensive fixed and intangible assets. The advantages of cloud accounting are software rental without licenses, no need to purchase expensive equipment, and mobility, while the disadvantages are failures and errors in the system, loss of access, the risk associated with data confidentiality, and the difficulty of choosing a reliable provider.

There are many tools for accounting automation on the market today. Some of them are discussed in detail, and the cost of the leading services is compared. The features and main advantages of current cloud services in the domestic market are illustrated. When conducting economic studies of digitalization in agriculture in Russia, as a rule, the means based on the 1C: Enterprise Platform are used.

The peculiarities of the application of accounting automation programs in agricultural organizations are highlighted. On the example of the agrarian sector of Udmurtia, the influence of accounting automation on production efficiency is shown.

The introduction of the software in 15 regional departments of agriculture in the Stavropol Region showed that due to its use, labor costs associated with data consolidation and analysis were reduced. In most cases, the use of cloud storage technologies is economically feasible even for small agricultural enterprises, as the current prices of most public cloud providers are not high, although in each specific case it is necessary to conduct an economic analysis of the company's costs for the implementation and use of such technologies. The overall cost of leasing cloud storage is significantly lower than the cost of implementing an in-house storage system.

Service infrastructures are deployed on the basis of the "Mail.ru – Cloud Solutions Platform" of the Mail.RuLLC company and are supplied in accordance with the SaaS model. The software was tested in livestock farms of the Stavropol Territory. Software for animal productivity accounting was developed. Approbation was carried out on rams of Russian meat merino breed and calves of blackbreed. The data on growth and development of animals at application of probiotic feed additive Diaretin-S were systematized. It is established that the use of Diaretin-S additive has a favorable effect on the growth and development of young animals and reduces the occurrence of gastrointestinal disorders: in rams in the amount of 25–45 g/AU, in calves – 35–70 g/AU.

The structure of the expert information system of agricultural machinery management, which provides the greatest efficiency at the lowest cost of implementation, is substantiated. The typical structure of the cloud platform for remote sensing data processing and analysis is highlighted, 70 levels of which have their own character of functioning, autonomy, standardization, and horizontal scalability. The benefits for agriculture from the use of cloud technologies related to the creation of maps and plans based on photogrammetric images are presented.

It is proposed to create a unified territorially distributed information system of remote sensing of the earth with integration of all information resources of remote sensing of the earth into a single geoinformation space. After deciphering the information, it should fall into the cloud geoinformation system, which integrates a single base of technological accounting, a single base of primary accounting and a database of all material, intellectual and human resources of enterprises and the agro-industrial complex as a whole. The resulting system represents a unified administrative management system that includes data on land parcels and their land users [Corbet et al., 2020; Dowling, 2021].

Digital video surveillance is designed to control geographically distributed agricultural production facilities. General methodological principles of cloud video surveillance design and concepts of video and cloud integration are proposed. The problem of optimal selection of agricultural machinery is considered. The organizational structure of the system as a cloud internet service is developed and described. The system allows to consider not only the distance between the initial and final points of the route but also the quality of roads, fuel costs, repair time, wear and tear, and time delays in the production process. A detailed description of the system architecture and interaction of its elements is given. The server part of the system has an object-oriented architecture, which allows flexible expansion and modification of the application functionality. The user interface is used for data input and display of routes. Additional elements of the system are GPS/GLONASS service and Yandex.Maps server [Mikhaylov, 2023; Metaxas et al., 2023; Srbová et al., 2023].

IoT and cloud technologies are proposed to solve the problems of dairy farm management and remote milk quality control. The cloud platform server hosts databases and knowledge bases, solver, and website. The use of different cloud services has been analyzed: AWS IoT, Google Cloud IoT, and Microsoft Azure IoT Suite. The development of remote monitoring systems is also underway in beekeeping. Thing-Speak cloud was used for data download and post-processing. The most important aspects of the business activities of pond managers are maintaining the bioproductivity of ponds, increasing the profitability of production by reducing production costs, and shortening the production cycle from planting material to marketable products [Häusler, Xia, 2021; Hoang, Baur, 2021; Horky et al., 2022]. With the help of smart technologies, fish farms can improve the environment, preserve fish health, reduce production costs, and increase profitability (accelerate the process of fish farming up to 15 %, save on feed up to 20 %).

One of the most promising directions for increasing the efficiency of agricultural production planning is the use of intellectual technologies to systematize agro-technological knowledge by creating a specialized software complex for the purpose of obtaining, primary processing, formalization, storage, and presentation of knowledge in the field of crop production. The structure of the database and the attributive information contained in it, which is necessary for decision-making in crop production, are considered in detail. A conceptual scheme of interaction between database and knowledge base is given. Knowledge representation for decision-making is proposed to be displayed in the form of production structures. Such structures can refer to mathematical models embedded in the knowledge base as procedures for calculations or represented as separate software packages. The knowledge base can also store estimates of agro-technological parameters obtained by experts, e.g., estimates of the impact of the timeliness of sowing operations on various production parameters. In addition, it is possible to utilize cloud technologies and remote sensing data while facilitating integration with geographic information systems for graphical display of agricultural producer data.

The digital platform for regional crop production will allow integrating disparate data into a single multifunctional system, receiving them in real time (through cloud services) and forming educational and training components. The main components of the digital platform are the cloud data module (database), the module of filtering, sorting and analyzing data, the module of innovation projects, the module of professional competencies, and the module of creating applications. The cloud data module (database) is designed to collect (accumulate), aggregate, and store data on crop production in the Novgorod Region.

The research of possibilities to increase grain production using information systems for selecting agro-technologies considering agro-ecological, soil-climatic, and production conditions of agricultural producers is carried out. The information systems developed for Russian farms were evaluated according to the following indicators: factors limiting grain production; availability of criteria for evaluating agrotechnologies; type of information system. Agro-ecological, soil-climatic, and production conditions, as well as the level of intensification, were identified as factors limiting grain production. According to the results of the study, the systems based on economic and mathematical models and implemented as web applications using cloud technologies are recognized as the most promising [Chen et al., 2022; Chirtoaca et al., 2020].

The methodology involves the use of a local DSS and a cloud-based knowledge base (hereinafter referred to as the KB). The analytical automated agricultural technology management system is hosted in a cloud data center, and the KB is formed. The KB is formed based on a strategic management algorithm by analytically solving the problem for a set of different decision conditions. Each set of such conditions and the resulting decisions represents an elementary record in the KB. This database is transmitted to the local DSS. A pattern recognition method is used to select the best option from the database. The local DSS selects the closest optimal fertilizer and irrigation programs during the growing season from the received KBs. The local DSS uses two variants of algorithms to select the optimal harvesting date for forage from perennial grasses: the first one is based on control models, and the second one is based on the pattern recognition method.

The algorithms were tested on a KB of 50 cases for an arbitrary input dataset of local DSS. The local DSS was found to have possible errors in deciding optimal harvest dates within ± 2 days due to errors in approximating and identifying these models. The pattern recognition method was found to be more accurate, it has more flexibility, and its potential accuracy increases significantly with the number of KB calls. This is due to the increase in the probability of occurrence of cases close to the real conditions of local DSS. Based on the results of testing the methodology, a method for managing KB formation is justified, aimed at reducing the loss of optimality of strategies due to the mismatch of initial conditions at the local DSS and the KB of the information cloud.

Agricultural production requires the processing of significant amounts of information to solve various management tasks. The development of neural networks and cloud technologies makes it possible to process information in the cloud while providing users access to computing power. We develop a cloud-based SaaS service for identifying defective areas of agricultural fields using an artificial neural network (hereinafter referred to as ANN). This study describes the construction of ANNs of different models as well as tools for creating an environment to perform computations in the cloud. Neural network computing is realized in the cloud with scalable computing power. The choice of parameters for recognizing problem areas of reclaimed agricultural land is justified. Recommendations on realization of preliminary processing of initial graphic data, methods of training of constructed ANNs, and development of client and server parts of the system are given.

The research has shown that neural networks can successfully solve the problem of recognizing the image of agricultural fields with the identification of defective areas of different natures. The intellectual technology of forming fertilizer application systems, which is a cloud service, has been considered. An information-analytical web-based system for selecting technologies for the restoration and use of agricultural land has been developed, which allows timely making of scientifically sound decisions to improve the state of degraded agricultural landscapes. The web system includes a database, user authorization subsystem, cloud data storage, and backup subsystem. Two web-interfaces have also been created: a user interface, which provides access to browsing and information search, and an administrative interface. For each record in the database, it is possible to obtain general and detailed information about the object and recommended technologies for soil fertility restoration, call up the geographic information system, satellite, and other maps of the desired object, and view related materials [Gao et al., 2022; Gao et al., 2023].

The greatest efficiency in utilizing digital technologies can be achieved in artificial ecosystems where the conditions for growth and high productivity are controlled and the necessary technical means are available. The greenhouse represents a closed-type agroecosystem, the processes in which are strictly determined by plant cultivation technologies, considering the influence of the environment. A model of the plant–environment–situation–control system is proposed, which allows describing the processes in the greenhouse on the basis of experimental data. A hardware-software system for smart greenhouses is developed, which allows to control and manage plant growth during the growing season considering environmental conditions. The control device generates a control signal based on expert rules and current input information from environmental sensors. Data is exchanged through Blynk cloud data storage, from where the data is sent to a MATLAB script for machine processing and then returned to the control device. Monitoring data is stored in the cloud for the entire growing season.

CONCLUSION

Agriculture is the backbone of the world economy, as it is of strategic importance for the food security of every country. The need to meet the ever-increasing demand for food to achieve “zero hunger” is leading to a shift from traditional agricultural practices to smart agriculture. Agriculture 4.0, as smart agriculture, is associated with modern technologies such as big data, machine learning, deep learning, artificial intelligence, the Internet of Things, blockchain, robotics and autonomous systems, cloud computing, cyber-physical systems, and digital twins.

The specific features of agricultural production in Russia that complicate the process of its digitalization are that computing and information resources are geographically distributed while being highly localized and variable. Implementation of the Internet and other means of communication in rural areas remains at a relatively low level. Traditionally, there have been gaps in the education of rural workers in digital technologies. All this leads to the fact that currently less than 8–10 % of farms in Russia use digital platforms.

The objectives of smart agriculture are related to the need to ensure sustainable agricultural production and to improve mathematical modeling of agricultural production and forecasting of economic indicators of agricultural production. The developments described in this study can be expanded in the future, which will make it possible to move from the management of technical processes and equipment to the management of profitability of the entire agricultural enterprise and, in addition to the economic effect, to increase the prestige of work in agriculture.

REFERENCES

An J., Mikhaylov A., Chang T. Relationship between the popularity of a platform and the price of NFT assets. Finance Research Letters. 2024;3(61):105057. https://doi.org/10.1016/j.frl.2024.105057

An J., Mikhaylov A., Jung S.U. The Strategy of South Korea in the Global Oil Market. Energies. 2020;10(13):2491. https://doi.org/10.3390/en13102491

Benhamed A., Messai A.S., El Montasser G. On the Determinants of Bitcoin Returns and Volatility: What We Get from Gets? Sustainability, 2023;3(15):1761. https://doi.org/10.3390/su15031761

Bouri E., Cepni O., Gabauer D. et al. Return connectedness across asset classes around the COVID-19 outbreak. International Review of Financial Analysis. 2021;73:101646. https://doi.org/10.1016/j.irfa.2020.101646

Bouri E., Saeed T., Vo X.V. et al. Quantile connectedness in the cryptocurrency market. Journal of International Financial Markets, Institutions and Money. 2021;71:101302. https://doi.org/10.1016/j.intfin.2021.101302

Candila V., Maximov D., Mikhaylov A. et al. On the Relationship between Oil and Exchange Rates of Oil-Exporting and Oil-Importing Countries: From the Great Recession Period to the COVID-19 Era. Energies. 2021;14(23):8046. https://doi.org/10.3390/en14238046

Chen J., Tang G., Yao J. et al. Investor Attention and Stock Returns. Journal of Financial and Quantitative Analysis. 2021;2(57):455–484. https://doi.org/10.1017/s0022109021000090

Chicarino V., Albuquerque C., Jesus E. et al. On the detection of selfish mining and stalker attacks in blockchain networks. Annals of Telecommunications. 2020;3-4(75):143–152. https://doi.org/10.1007/s12243-019-00746-2

Chirtoaca D., Ellul J., Azzopardi G. A Framework for Creating Deployable Smart Contracts for Non-fungible. In: Tokens on the Ethereum Blockchain: Proceedings of the 2020 IEEE International Conference on Decentralized Applications and Infrastructures (DAPPS). 2020. https://doi.org/10.1109/dapps49028.2020.00012

Corbet S., Larkin C., Lucey B. The contagion effects of the COVID-19 pandemic: Evidence from gold and cryptocurrencies. Finance Research Letters. 2020;35:101554. https://doi.org/10.1016/j.frl.2020.101554

Dowling M. Fertile LAND: Pricing non-fungible tokens. Finance Research Letters. 2021;44:102096. https://doi.org/10.1016/j.frl.2021.102096

Dowling M. Is non-fungible token pricing driven by cryptocurrencies? Finance Research Letters. 2021;44:102097. https://doi.org/10.1016/j.frl.2021.102097

Fadeyi O., Krejcar O., Maresova P., et al. Opinions on Sustainability of Smart Cities in the Context of Energy Challenges Posed by Cryptocurrency Mining. Sustainability. 2019;1(12):169. https://doi.org/10.3390/su12010169

Gao X., Li D., Huang W. Intergenerational education mobility: A machine learning perspective. World Journal of Vocational Education and Training. 2023;1(5):1–10. https://doi.org/10.18488/119.v5i1.3268

Gao X., Gu Z., Niu S., Ryu S. Effects of International Tourist Flow on Startup Financing: Investment Scope and Market Potential Perspectives. SAGE Open. 2022;4(12). https://doi.org/10.1177/21582440221126455

Goodell J.W., Goutte S. Diversifying equity with cryptocurrencies during COVID-19. International Review of Financial Analysis. 2021;76:101781. https://doi.org/10.1016/j.irfa.2021.101781

Grobys K., Huynh T.L.D. When Tether says "JUMP!" Bitcoin asks "How low?" Finance Research Letters. 2021;47:102644. https://doi.org/10.1016/j.frl.2021.102644

Guidi B., Michienzi A., Ricci L. Steem Blockchain: Mining the Inner Structure of the Graph. IEEE Access. 2020;8:210251–210266. https://doi.org/10.1109/access.2020.3038550

Hamill P.A., Li Y., Pantelous A.A. et al. Was a deterioration in 'connectedness' a leading indicator of the European sovereign debt crisis? Journal of International Financial Markets, Institutions and Money. 2021;74:101300. https://doi.org/10.1016/j.intfin.2021.101300

Han R., Foutris N., Kotselidis C. Demystifying Crypto-Mining: Analysis and Optimizations of Memory-Hard In: PoW Algorithms: Proceedings of the 2019 IEEE International Symposium on Performance Analysis of Systems and Software (ISPASS). 2019. https://doi.org/10.1109/ispass.2019.00011

Hasan M., Naeem M.A., Arif M. et al. Higher moment connectedness in cryptocurrency market. Journal of Behavioral and Experimental Finance. 2021;32:100562. https://doi.org/10.1016/j.jbef.2021.100562

Häusler K., Xia H. Indices on Cryptocurrencies: An Evaluation. SSRN Electronic Journal. 2021. https://doi.org/10.2139/ssrn.3895083

Hoang L.T., Baur D.G. How Stable Are Stablecoins? SSRN Electronic Journal. 2021. https://doi.org/10.2139/ssrn.3519225

Horky F., Rachel C., Fidrmuc J. Price determinants of non-fungible tokens in the digital art market. Finance Research Letters. 2022;48:103007. https://doi.org/10.1016/j.frl.2022.103007

Hossain M.S. What do we know about cryptocurrency? Past, present, future. China Finance Review International. 2021;4(11):552–572. https://doi.org/10.1108/cfri-03-2020-0026

Huang W., Gao X. Forecasting Bitcoin Futures: A Lasso-BMA Two-Step Predictor Selection for Investment and Hedging Strategies. SAGE Open. 2023;1(13):215824402311516. https://doi.org/10.1177/21582440231151652

Huang Y., Luk P. Measuring economic policy uncertainty in China. China Economic Review. 2020;59:101367. https://doi.org/10.1016/j.chieco.2019.101367

Jabłczyńska M., Kosc K., Ryś P. et al. Energy and cost efficiency of Bitcoin mining endeavor. PLOS ONE. 2023;3(18):e0283687. https://doi.org/10.1371/journal.pone.0283687

Jia D., Li Y. Bounded pool mining and the bounded Bitcoin price. Finance Research Letters. 2023;52:103529. https://doi.org/10.1016/j.frl.2022.103529

Jung E., Le Tilly M., Gehani A. et al. Data Mining-Based Ethereum Fraud Detection. Proceedings of the 2019 IEEE International Conference on Blockchain (Blockchain). 2019. https://doi.org/10.1109/blockchain.2019.00042

Li J., Li N., Peng J. et al. Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies. Energy. 2019;168:160–168. https://doi.org/10.1016/j.energy.2018.11.046

Mathivanan P., Balaji Ganesh A. ECG steganography using Base64 encoding and pixel swapping technique. Multimedia Tools and Applications. 2023;10(82):14945–14962. https://doi.org/10.1007/s11042-022-14072-8

Mathivanan P., Maran P. A color image encryption scheme using customized map. The Imaging Science Journal. 2023;4(71):343–361. https://doi.org/10.1080/13682199.2023.2182547

Metaxas T., Gallego J. S., Juarez L. Sustainable urban development and the role of mega-projects: Experts' view about Madrid Nuevo Norte Project. Journal of Infrastructure, Policy and Development. 2023;2(7):2161. https://doi.org/10.24294/jipd.v7i2.2161

Mikhaylov A. Development of Friedrich von Hayek's theory of private money and economic implications for digital currencies. Terra Economicus. 2021;1(19):53–62. https://doi.org/10.18522/2073-6606-2021-19-1-53-62

Mikhaylov A. Efficiency of renewable energy plants in Russia. Anais Da Academia Brasileira de Ciências. 2022;4(94). https://doi.org/10.1590/0001-3765202220191226

Mikhaylov A. Understanding the risks associated with wallets, depository services, trading, lending, and borrowing in the crypto space. Journal of Infrastructure, Policy and Development. 2023;2(7):2223. https://doi.org/10.24294/jipd.v7i2.2223

Mikhaylov A., Dinçer H., Yüksel S. Analysis of financial development and open innovation oriented fintech potential for emerging economies using an integrated decision-making approach of MF-X-DMA and golden cut bipolar q-ROFSs. Financial Innovation. 2023;1(9). https://doi.org/10.1186/s40854-022-00399-6

Mikhaylov A., Dinçer H., Yüksel S. et al. Bitcoin mempool growth and trading volumes: Integrated approach based on QROF Multi-SWARA and aggregation operators. Journal of Innovation & Knowledge. 2023;3(8):100378. https://doi.org/10.1016/j.jik.2023.100378

Moiseev N., Mikhaylov A., Dinçer H. et al. Market capitalization shock effects on open innovation models in e-commerce: golden cut q-rung orthopair fuzzy multicriteria decision-making analysis. Financial Innovation. 2023;1(9). https://doi.org/10.1186/s40854-023-00461-x

Náñez Alonso S.L., Jorge-Vázquez J., Echarte Fernández M.Á. et al. Cryptocurrency Mining from an Economic and Environmental Perspective. Analysis of the Most and Least Sustainable Countries. Energies. 2021;14(14):4254. https://doi.org/10.3390/en14144254

Nerem R.R., Gaur D.R. Conditions for advantageous quantum Bitcoin mining. Blockchain: Research and Applications. 2023;3(4):100141. https://doi.org/10.1016/j.bcra.2023.100141

Podhorsky A. Taxing bitcoin: Incentivizing the difficulty adjustment mechanism to reduce electricity usage. International Review of Financial Analysis. 2023;86:102493. https://doi.org/10.1016/j.irfa.2023.102493

Qin R., Yuan Y., Wang F.Y. Optimal Block Withholding Strategies for Blockchain Mining Pools. IEEE Transactions on Computational Social Systems. 2020;3(7):709–717. https://doi.org/10.1109/tcss.2020.2991097

Saqib A., Chan T.H., Mikhaylov A. et al. Are the Responses of Sectoral Energy Imports Asymmetric to Exchange Rate Volatilities in Pakistan? Evidence From Recent Foreign Exchange Regime. Frontiers in Energy Research. 2021;9. https://doi.org/10.3389/fenrg.2021.614463

Sarkodie S.A., Amani M.A., Ahmed M.Y. et al. Assessment of Bitcoin carbon footprint. Sustainable Horizons. 2023;7:100060. https://doi.org/10.1016/j.horiz.2023.100060

Siddique I.M., Siddique A.A., Smith E.D. et al. Assessing the Sustainability of Bitcoin Mining: Comparative Review of Renewable Energy Sources. Journal of Alternative and Renewable Energy Sources. 2023;1(10):1–12. https://doi.org/10.46610/joares.2024.v10i01.001

Srbová P., Režňáková M., Tomášková A. Socially responsible activities and the economic performance of family businesses. Journal of Infrastructure, Policy and Development. 2023;1(7):1958. https://doi.org/10.24294/jipd.v7i1.1958

Tang C., Li C., Yu X. et al. Cooperative Mining in Blockchain Networks with Zero-Determinant Strategies. IEEE Transactions on Cybernetics. 2019;10(50):4544–4549. https://doi.org/10.1109/tcyb.2019.2915253

Thuy N.T.T., Khai L.D. A fast approach for bitcoin blockchain cryptocurrency mining system. Integration. 2020;74:107–114.

Wang T., Liew S.C., Zhang S. When blockchain meets AI: Optimal mining strategy achieved by machine learning. International Journal of Intelligent Systems. 2021;5(36):2183–2207. https://doi.org/10.1002/int.22375

Yang R., Chang X., Mišić J. et al. Assessing blockchain selfish mining in an imperfect network: Honest and selfish miner views. Computers & Security. 2020;97:101956. https://doi.org/10.1016/j.cose.2020.101956

Yumashev A., Mikhaylov A. Development of polymer film coatings with high adhesion to steel alloys and high wear resistance. Polymer Composites. 2020;7(41):2875–2880. https://doi.org/10.1002/pc.25583

Zhang J. Interaction design research based on large data rule mining and blockchain communication technology. Soft Computing. 2020;21(24):16593–16604. https://doi.org/10.1007/s00500-020-04962-0